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THE SERVICES OF BENJAMIN PEIRCE TO AMERICAN MATHEMATICS AND ASTRONOMY.

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FOR POPULAR ASTRONOMY.

It is related that when Dr. Bowditch was preparing the manuscript of his translation of Laplace's *Mécanique Céleste* a lad by the name of Benjamin Peirce with a playmate happened to enter his library in Salem; while glancing over some of the pages which the illustrious translator had finished young Peirce exclaimed, "here is a mistake." The great mathematician examined the passage in question and found that his young friend had indeed detected a genuine error. This circumstance is said to have aroused Bowditch's interest in the brilliant young Peirce. It did not take Bowditch long to discover his extraordinary talents, and a casual acquaintance soon grew into an intimate and professional friendship. Peirce became the disciple, and subsequently the logical successor, of Bowditch, who predicted that his favorite student would some day be the foremost mathematician of his country.

Benjamin Peirce was born at Salem, Massachusetts, April 4th, 1809, the third of the four children of Benjamin Peirce and his wife, a sister of the Rev. Dr. Nichols of Portland, Maine. The elder Mr. Peirce graduated at Harvard in 1801, with the highest honors of his class. For a time he was a merchant in Salem but in later years inclined towards letters: from 1826 to 1831—the year of his death—he was college librarian and wrote a history of Harvard University from 1639 to the time of the American Revolution.

Benjamin Peirce Junior graduated from Harvard with the highest honors in 1829, and his college days thus brought him into contact with such classmates as Geo. T. Bigelow, W. H. Channing, B. R. Curtis, Oliver Wendell Holmes and James Freeman Clarke.

While still an undergraduate Peirce pursued his studies under the direction of Nathaniel Bowditch, and when the immortal translation of the *Mécanique Céleste* came to the press this de-

voted student rendered important services in critically reading and correcting the proofs. Those who have had occasion to make a profound examination of the work can bear witness to the very small number of errors which escaped both Bowditch and Peirce.

In 1831, after young Peirce had taught two years at Round Hill, Northampton, he was appointed tutor in mathematics at Harvard University; his connection with the college continued for the unprecedented period of forty-nine years. He became university professor of mathematics and natural philosophy in 1833 and during the next thirteen years issued a series of valuable text-books on geometry, algebra, trigonometry, and "curves, functions and forces," which were filled with new methods and have made a lasting impression upon the educational work of this country. In 1842 Peirce was appointed Perkins professor of mathematics and astronomy and continued to hold this position for thirty-eight years.

Professor Peirce's life may be said to have been as a whole remarkably fortunate and happy. He was married in 1833, and at the time of his death, his wife, a daughter and three distinguished sons survived him. His eldest son, James Mills Peirce, university professor of mathematics at Harvard, and dean of the graduate school, has long been celebrated as one of the most eminent mathematicians of the country; another son Dr. Chas. S. Peirce, who inherited his father's talents to a remarkable degree, has been professor in Harvard and Johns Hopkins, and now resides in Milford, Pa.; the third son, H. H. D. Peirce is a business man connected with a large firm in New York City.

Peirce's long career was one of great activity. In his first years as professor of mathematics he was busily occupied with the composition of mathematical text-books based upon new and original methods. In 1842 he entered somewhat more particularly into physical problems, and published papers on the motion of a top, Espy's theory of storms, and adopted the epicycles of Hipparchus to the analytical form now used by astronomers. The great comet of 1843, which was distinctly visible at midday, and attracted great popular attention, gave Professor Peirce the opportunity, by a few striking lectures in Boston, to arouse a public interest in astronomy which led to the founding of the Observatory at Cambridge. This was the first great and efficient Observatory to be established in the United States, and its value to American science may be judged from the fact that only a few years before Dr. Bowditch had declared that "America has as yet no

Observatory worthy of mention." The Observatory of Harvard College, equipped with a 15-inch refractor, (then the most powerful in the world) and other necessary apparatus, had also the good fortune to secure a Director of scientific training, and hence for many years Harvard College became the natural center of astronomical activity in the United States. Peirce's work on the orbit of this great comet brought him into close relations with the lamented Sears C. Walker, and prepared the way for their still more important researches on the orbit of Neptune. For several years after the discovery of this planet by Galle, the English and French were occupied with fierce contentions relative to the honors due to Adams and Leverrier and the discussion of the orbit was left almost entirely to Professor Peirce and Sears C. Walker. The latter boldly undertook the investigation of the orbit, and soon succeeded in tracing the planet's approximate path along the zodiac during the 18th century. He thus found that it had been previously observed by La Lande and Lemonnier as a fixed star. With the positions of Neptune thus secured at distant epochs, the orbit could be found with considerable precision, while without these data, accidentally recorded by the French, and brought to light by the genius of Walker, astronomers must have waited for half a century before getting even an approximate orbit of the planet. These important researches inspire the belief that American astronomy has seldom sustained a more serious loss than in the early death of Walker, whose career was cut short not unlike that of Tobias Mayer. The memory of this remarkable astronomer ought to be held in respect by all who desire to do justice to elevated character and to meritorious scientific work.

Peirce took up a theoretical examination of the processes by which Adams and Leverrier had predicted the place of the unknown body, and was led to the conclusion that while the processes involved had been exact, wonderfully laborious, and deserving of all honor, yet the result was not decisive, as two possible planets would have satisfied the conditions of the problem. The two bodies were, first, the theoretical planet predicted by Adams and Leverrier, having a larger mass at a greater distance (assumed to conform to Bode's law); and second, the actual Neptune discovered by Galle with an inferrior mass and revolving at a smaller distance. It is easy to see that the purturbations arising from two such bodies would be almost exactly the same during the interval since the discovery of Uranus, but this result could not hold true indefinitely. The two bodies were

in the same direction from the Sun only in 1846, and if Neptune had not been discovered at that epoch the calculations must have required sensible modifications in the course of a few years. This result is very obvious to one who is familiar with the theory of perturbations, but Peirce subjected the question to computation in order to leave no doubt of its entire rigor. When Peirce's results were announced to the American Academy they gave rise to much discussion and were even vigorously contested by several eminent mathematicians of Europe; but astronomers have since recognized the justice of his criticisms which were not meant to detract from, but rather to supplement the, glorious achievements of Adams and Leverrier. The reasoning of these two eminent astronomers had assigned a sufficient, but not the only possible explanation, of the purturbations of Uranus. Yet when Peirce reached this conclusion and showed that the discovery in 1846 was a "happy accident"—since the two bodies would be in the same longitude only at that time—President Edward Everett, of Harvard college, "hoped the announcement would not be made public; nothing could be more improbable than such a coincidence." "Yes," replied Peirce, "but it would be still more wonderful if there were an error in my calculations."

In 1849 Professor Peirce was made consulting geometer to the *American Ephemeris and Nautical Almanac*, which had just been established at Cambridge. The important services which he rendered to this publication during the next thirty years enabled it to take rank with the highest authorities in the world. Peirce's attention at this epoch was devoted almost exclusively to the science of astronomy. In 1852 he published, for the use of the *American Ephemeris*, lunar tables which came into general use among astronomers and for many years continued to give good positions of the Moon. From 1852 to 1855 he was occupied with an elaborate investigation of the constitution of Saturn's rings. Professor G. P. Bond had seen the rings apparently divide themselves and reunite, and had been led to the conclusion that they could not be solid, as Laplace had assumed in his theory of their constitution. Peirce investigated the question anew, and showed that an unsymmetrical solid ring, such as Laplace had postulated, could not be kept in stable equilibrium by the action of the planet and satellites; and that while fluid rings could not be sustained by the action of the planet alone, sufficiently large and numerous satellites might contribute the necessary conditions of stability. He therefore concluded that the rings of Saturn are thin masses of fluid kept in equilibrium by the action

of the planet and its eight satellites. We ought to add that while mathematicians now hold this conclusion to be dynamically unsound, it was at the time a very important step in advance of Laplace and doubtless stimulated the investigation of Clerk Maxwell in 1859, which revived the old theory of Cassini and showed that the rings must necessarily be of a meteoric character, made up of single discrete particles, each revolving as an independent satellite. Peirce's treatment of the occultations of the Pleiades is equally original and suggestive, and brings to light a method which enables us to deduce from such observations the figures of both Earth and Moon; in this respect his theory of the occultations of the Pleiades is closely analagous to the method developed by Laplace for deriving the figure of the Earth from the lunar perturbations depending upon the oblateness of the terrestrial spheroid. Peirce's influence as a man of science rapidly extended throughout the Republic, and in 1855 he was made one of the Scientific Council entrusted with the organization of the Dudley Observatory. Dr. Benjamin Apthorp Gould, who had qualified himself under the most eminent astronomers in Europe, and had been a favorite student of Gauss, at Göttingen, was called to the directorship and at once placed the Observatory in the very front ranks of scientific institutions. His establishment of the *Astronomical Journal* and the great eminence to which his name and reputation raised the Observatory, aroused the jealousy of certain trustees, a result which so often happens in a community dominated by ignoble and small-minded men! In the subsequent controversy the Director maintained the unshaken support of the most illustrious scientific men of the country—Benjamin Peirce, Joseph Henry and A. D. Bache, who published a defense of his administration. Without commenting on the meritorious but unsuccessful effort of the Scientific Council—Peirce, Henry and Bache—to conserve the real interests of science, it may yet be permissible to remark that if the name of any one of these trustees shall escape the just fate of oblivion it will only be through that old injustice to Gould, whose incomparable scientific work must necessarily remain luminous through coming centuries.

Peirce was president of the American Association for the Advancement of Science at the Cleveland meeting in 1853. In 1847 he received the degree of LL. D. from the University of North Carolina and in 1867 from Harvard College. He was a member of the American Academy of Arts and Sciences, and of the American Philosophical Society, and was elected an associate of the Royal

Astronomical Society in 1847. In 1852 he was made an honorary fellow of the Royal Society of London. When the National Academy of Sciences was established in 1863, Peirce was one of the original members appointed by congress to organize the first scientific body of the United States, in which he exerted a strong and lasting influence for maintaining the highest standard of scientific excellence.

The attention of Peirce was for many years much devoted to Geodesy. He assisted greatly in the work of the coast survey while under the direction of Bache and in 1867 was himself appointed superintendent. Peirce held the office for seven years; his administration was distinguished by the introduction of improved scientific methods, by a wise selection of men for the working staff, and by remarkable practical executive ability. It has been said of him that he showed the applicability of the theory of the Stoics in our own time—the really great man shows himself great by any and every standard.

He detected important errors in former determinations of the force of gravity, due to defective supports of the pendulums employed, inspired the highest confidence in the work of the Survey, and exercised a powerful influence in impressing upon congress the dignity and importance of the work which had been undertaken by the government of the United States. He realized that our position among the nations of the earth required that a scientific work of national importance should be adequately supported by congress; and on the other hand when funds had been appropriated for the Survey he exercised a careful supervision to insure legitimate and proper expenditures.

Peirce presented many striking papers to various societies, academies and institutions, but unfortunately most of these have been published only in abstract. We may mention among these an investigation of the forms of stable equilibrium for a fluid mass enclosed in an extensible sack floating in another fluid, a problem of interest in connection with embryology. He treated also the discontinuous motion of a billiard ball, the motion of a sling, and showed in the vegetable world the demonstrable presence of an intellectual plan; that what is known as Phyllotaxis involved an algebraic idea since shown to be the solution of a physical problem and likely to prove of great importance to the future of botany and zoölogy.

In 1857 Peirce published his "System of Analytical Mechanics" including "the latest researches of the great geometers in their most exalted forms of thought," a work which took high rank

on both sides of the Atlantic. It was announced at the same time that the work was to be continued and that the subsequent volumes would be entitled respectively, "Celestial Mechanics," "Potential Physics" and "Analytic Morphology;" but unfortunately the plan was never carried out.

As one of the original members of the National Academy of Sciences Peirce from time to time communicated to that illustrious body various papers on pure mathematics and theoretical physics, especially on the heat of the Sun. In 1870 certain friends in the Coast Survey caused 100 copies of his communications to the National Academy on "Linear Associative Algebra" to be lithographed and brought out in a form convenient for the use of mathematicians. These researches are regarded as his most original and precious contributions and are justly famed in all the countries of the world. For the sake of brevity suffice it to say that the investigation deals with nearly a hundred possible forms of Algebra of which only three are in use, (1) Ordinary Algebra, (2) the Calculus of Newton and Leibnitz and (3) the Quaternions of Hamilton. He outlines the great features of these many new species of Algebra with scarcely a comment and only patient study enables the reader to comprehend the great depth of his author.

Succinctness of statement and brevity of exposition have always been a conspicuous trait of his genius, and this characteristic led not a few to complain of obscurity in his writings; the same complaint was made regarding his teaching, but such an obstacle to the student is inconsiderable in the presence of so amiable, so enthusiastic and so magnetic a teacher. Peirce, like many other great men, constantly over-rated the ability of his students; he assumed that they could follow wherever he led. But in spite of this difficulty so great was the devotion of his students in their admiration for his enthusiastic, generous and exalted character, that he was always the center of a great influence. The steadfast admiration felt towards him by his intimate friends and students was due to his moral as well as his intellectual character. Making the concession that he occasionally exhibited a touch of intolerance towards pretentious mediocrity, they would allow nothing in him to be aught else than of the highest quality. His great nobility of character frequently gave his students credit for what was in reality his own. He robbed himself of fame in two ways: by giving the credit of his discoveries to those who had merely suggested the line of thought, and by neglecting to write out and publish his own developments.

Peirce's students include the most eminent astronomers and mathematicians of our day, and his noble and generous influence on the development of American science can hardly be overestimated. Among those who came under his influence and guidance we may name: Dr. B. A. Gould, Profesor J. Winlock, Dr. S. C. Chandler, Professor S. Newcomb, Dr. G. W. Hill, Professor W. Ferrell, Professor G. W. Hough and Professor Van Vleck.

It will be seen from this array of illustrious names that Harvard was at one time the center of astronomical inspiration, and exercised a vast influence in the higher development of American Astronomy.

Well might Peirce's death be deeply lamented both in Europe and America and above all at Harvard College! Lord Kelvin in an address to the British Association referred to Peirce as the "Founder of higher mathematics in America," and Cayley styled him the "Father of American geometry."

His death was equally lamented by the public and given conspicuous notice by the leading journals of the country. The *Boston Daily Advertiser* of Oct. 7th, 1880, said editorially: "The death of Professor Benjamin Peirce is a great and a national loss; for he was the Nestor of American mathematicians, and the historic transition from the illustrious Nathaniel Bowditch to the present generation of mathematical minds." Similar press notices appeared in many other papers, and appropriate resolutions were adopted by the faculty of Harvard and by the president and fellows, lamenting the great and irreparable loss which had befallen the College.

It seems of interest to recall the circumstances of the last illness of the illustrious mathematician. Peirce had throughout life maintained a lively interest in every form of intellectual activity, and during the winter of 1879–80 was still active in many directions. His great powers seemed to be still employed in the study of cosmical physics, and he had announced a new course in that subject for the following year. With the assistance of a favorite student he resumed with unusual enthusiasm the study of the great comet of 1843, and undertook a complete inquiry into all its successive appearances from the beginning of astronomical records, incited thereto by hearing of the remarkable observation, strongly recalling that comet, made in South America by his life long friend Dr. Benjamin Apthorp Gould. But it is probable that his renewed activity was but the outward sign of a presentiment of the approaching end. His serious illness began on June 25th, 1880, and from this time his condition grew gradually worse. He passed away on Wednesday morning, Oct. 6th, 1880.

Distinguished throughout life by a stoicial view of death, which did not permit him to mourn when it came to others or to dread for himself, he maintained the same temper to the end.

The funeral took place at Appleton chapel, on Oct. 9th, and was the occasion of an impressive gathering of scholars who desired to pay a last tribute to this great and good man, justly ranked among the most illustrious of the Earth. The attendance included a full representation of the faculties and governing boards of the University; a large deputation of officers of the United States Coast and Geodetic Survey, headed by the Superintendent and Chief Assistant; delegations of eminent professors from Yale College and Johns Hopkins University; members of the class of 1829, and numerous other friends of the deceased.

The pall-bearers were: President Chas. W. Elliott; ex-president Thomas Hill, of Portland; Captain C. P. Patterson, superintendent of the U. S. Coast and Geodetic Survey; Professor J. J. Sylvester, of the Johns Hopkins University; Hon. J. Ingersoll Bowditch; Professor Simon Newcomb, superintendent of the *American Ephemeris and Nautical Almanac*; Dr. Oliver Wendell Holmes; Professor J. Lovering, and Dr. Morrill Wyman.

It was certainly fitting that one who had played so great and so noble a part in the advancement of American science should receive an appropriate homage from his grateful countrymen.

As Fourier exclaims in his eulogy on Laplace, "it is undoubtedly beautiful, it is glorious, it is worthy of a powerful nation, to ordain brilliant honors in memory of its celebrated men." Benjamin Peirce was a mathematician and astronomer of the highest type, worthy to be ranked with the greatest intellects of any age or country. We need not hesitate to compare his achievements with those of the greatest successors of the immortal Newton. It was not given to him to create entirely new sciences as did the early pioneers of modern thought; but the great scope of his work and above all the extraordinary originality displayed in his "Linear Associative Algebra" will transmit his name to the most remote ages. While on the other hand his noble work in the education and inspiration of astronomers and mathematicians and in behalf of the dignity of American science as a whole, will endear his memory to his grateful countrymen while the stars shall go through their wonted courses in the heavens.

As England has done honor to her Newton and Herschel, France to her Laplace and Lagrange, Germany to her Bessel and Gauss, so let America also be grateful for the priceless heritage she has received from her Bowditch and Peirce!

THE UNIVERSITY OF CHICAGO, Sept. 18, 1895.

PHOTOGRAPHING THE MILKY WAY.

H. C. WILSON.

For Popular Astronomy.

The great irregular belt of light, stretching across the sky, which we call the galaxy or Milky Way, has always been an object of interest, of admiration and wonder, I suppose, to those whose thoughts at all turn to things above us. To the astronomer the structure of the galaxy is a problem of the deepest interest. Since the invention of the telescope it has been known that the light of the Milky Way, the greater part of it at least, comes from countless numbers of stars, individually invisible to the eye, but collectively giving a bright glow to the parts of the sky where they are crowded most thickly together.

The Milky Way is not a belt of uniform brightness, but there are irregular dark areas running all through it, breaking it up into bright patches or clouds, of various shapes and sizes. A number of attempts have been made to represent these irregularities of the galaxy upon the star maps, but generally with ill success. It is very difficult for a draftsman to represent the delicate shadings which are necessary.

In order to catch the fainter details the eye must be keenly sensitive, must have been in total darkness for some time. The drawing requires light, the presence of which destroys to a considerable degree the sensitiveness of the eye. It must therefore be done largely from memory. Either the work must be unreliable or an immense amount of time must be consumed in verifying every part of the details, by repeated comparison of the drawing with the sky, under the most favorable conditions. Even then personal bias is liable to affect the result. Details once seen are likely to be seen the same the next time by the same person, whether correct or not.

The most perfect pieces of work of this kind have been completed recently by Dr. Otto Boeddicker at Birr Castle, Parsontown, Ireland, and M. Eaton at Paris. Each of these gentlemen spent several years in the production of a map which should represent all that can be seen of the galaxy with the naked eye, and their results are far ahead of anything that has gone before. They are wonderful for the amount of detail which they show, but they do not agree with each other. The one shows much more detail than is ordinarily seen with the naked eye, the other less than is seen under the best conditions.

When it was found that photography could be applied to the mapping of the stars, it was expected that this would at once give us an accurate means of determining the form of the Milky Way. The first attempts, however, were diappointing. The telescopes employed were of too long focus, giving pictures on too large a scale and taking in too small areas of sky. The exposures were as a rule too short and the very faint stars, which contribute largely to the glow of the Milky Way, failed to register themselves. The dark channels appeared almost as full of stars as did the bright areas.

In 1889 Professor E. E. Barnard, at Lick Observatory, began taking photographs of the Milky Way with an old portrait lens, which for many years had done service in a San Francisco photograph gallery. This lens, which was made in 1859, by Willard, of New York, is of 6 inches aperture and 31-inches focus. Though small and insignificant, compared with the regular photographic telescopes, it was found to be especially adapted to photographing the Milky Way, because from its short focus it took in a large area of sky, crowding the stars into a smaller space upon the photographic plate, and giving to the whole more nearly the naked eye appearance. Mr. Barnard too was a skillful photographer, having been brought up to that trade, and in his hands the chemicals were made to do their full part in developing the image upon the sensitive plate. Since that time, with the same lens reground by Brashear, he has obtained many magnificent pictures of the cloud forms of the galaxy. Dr. Max Wolf, in Germany, and Dr. Russell, in Sydney, Australia, have also done excellent work in the same line.

The writer began experimenting in celestial photography in 1888, but made no long exposure until 1892, when a number of good photographs of the Orion nebula and constellation were obtained with the 8-inch Clark refractor and a Darlot lantern lens of 2½ inches aperture and about 8-inches focus. The Clark refractor is provided with a correcting lens adapting it to the photographic rays, and gives very sharp images of the stars when the seeing is fair. The Darlot lens or combination of lenses, for there are four of them, is not especially corrected for rays coming from the distance of the stars. The images are sharp over the central portion of the field but towards the edges they are badly distorted, as may be seen in the left hand picture in Plate IV. This lens is, however, quite well adapted to photographing the cloud forms of the Milky Way. The scale of picture is small and the field large, taking in about 20° in diameter, over which the

definition is fairly good. The lens was mounted in a small wooden box and strapped with iron bands to the tube of the 8-inch telescope. In order to guide these two cameras, for the 8-inch telescope is really a large camera, a 4-inch telescope was strapped in the same way to the latter. The 4-inch was provided with an eye-piece having two rather coarse crosshairs, which might be illuminated or not at will, so that the observer could readily adjust the telescopes and keep the light of each star continually falling on the same portion of the sensitive plate. In this way exposures of from two to four hours were made.

The attempts with this improvised apparatus were so successful that we were encouraged to have the mounting of the 8-inch remodeled and a permanent guiding telescope, of 5 inches aperture and of the same focal length with the 8-inch, rigidly attached to the latter. A new camera was purchased with lenses of 6 inches aperture and focus 31 inches from the back lens to the plate, designed especially for stellar work by Professor C. S. Hastings and constructed by Mr. J. A. Brashear. This camera is rigidly attached to the 8-inch telescope, and the performance of the combination is admirable. The exposure may now be prolonged indefinitely, extending over as many nights as the observer pleases, the only limitations being the weather and the observer's lack of confidence in the sensitive plates used.

The new camera takes in, upon an 8×10 plate, a field of twelve degrees diameter, with good definition over the whole field. The star images are perfectly round over the whole plate, the only distortion being an enlargement of the photographic discs toward the edges.

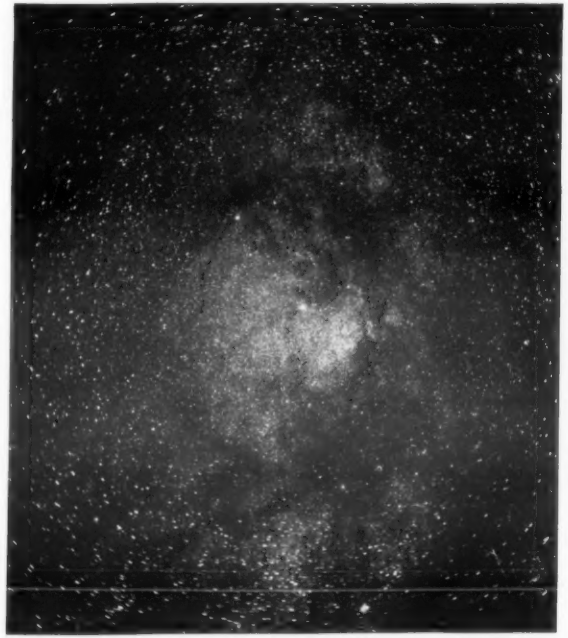
On securing the new camera we did not discard the old one but left it attached to the telescope, so that now three pictures are obtained at the same time, the same object being shown at the center of each but on a very different scale. We present in this number of POPULAR ASTRONOMY three such photographs, taken with two exposures of four hours each, on the nights of June 26 and 27, 1895. In the center of each is the well known cluster in the constellation Scutum Sobieskii, a beautiful object as seen with good telescope.

The right hand picture in Plate IV is from the photograph taken with the 8-inch telescope and shows the cluster much as it appears in an ordinary telescope under low power. In the original negative the stars are small and round and will bear magnifying, but in the engraving the meshes of the screen confuses them and many are wholly obliterated. None of the stars

PLATE IV.

N

E



S

THE MILKY WAY IN SCUTUM SOBIESKII.

Photographed with the 2½-inch Darlot Lantern Lens at Goodsell Observatory by H. C. Wilson. Exposure 8 hours.

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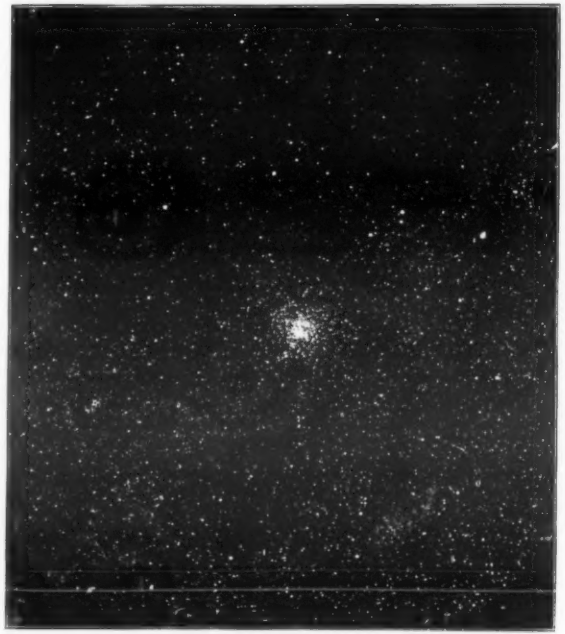
E W



S

THE STAR CLUSTER IN SCUTUM SOBIESKII.

Photographed with the 8-inch Clark Refractor at Goodsell Observatory, by H. C. Wilson. Exposure 8 hours.

PLATE V.

W

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S

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THE MILKY WAY IN THE CONSTELLATION SCUTUM SOBIESKII.

Photographed with the 6-inch Brashear camera at Goodsell Observatory, Northfield, Minn., by H. C. Wilson.

Exposure 8 hours.

on this plate are visible to the naked eye, and but few of them can be seen with a good opera-glass. The diameter of the field shown is about two degrees, or four times the Moon's diameter. The dark and bright patches shown in the same area about the cluster in the other pictures are not evident here because the stars are so scattered.

The left hand picture in Plate IV is from the negative exposed in the 2½-inch camera. The cluster will be recognized as a white spot in the center. The field is so large that it takes in the whole of the constellation Scutum, and parts of Aquila on the north-east, Sagittarius on the south and Serpens on the west. Not many bright stars are in this region and it is hard to pick them out from such a multitude of fainter ones. The conspicuous star, about three-fourths of an inch toward the east and a little north of the cluster, is λ Aquilæ. North and a little west of this are *h* and *g* Aquilæ. The bright star near the right edge of the cut, a little below the middle, is η Serpentis. Those who have the numbers of POPULAR ASTRONOMY for 1894 will find these stars on the map in the September number. It is possible to pick out quite a number more of the naked eye stars which are on the maps, but these are enough to show the scale of the photograph. The important point to be noticed is the variegated configuration of the bright and dark parts of the Milky Way. The whole constellation of Scutum becomes one superb star cluster, surrounded and pierced through in many places by a network of dark lanes or channels. The brightness of the background in this picture is not due to nebulous matter, but to the illumination of our atmosphere by diffused starlight. The lens of short focus condenses this light so that, with such long exposure, it is able to produce a perceptible effect upon the sensitive plate.

Plate V is from the negative exposed in the 6-inch camera. It takes in only the one great cloud of stars in Scutum. The contrasts in this picture are stronger so that the sky-light background is obliterated although it is quite noticeable in the original. The dark spaces are really dark so far as the light of stars is concerned. Even those little ones, which appear close to the central cluster, are not accidents of printing, but are actual blank spaces in the midst of a region which seems to be literally packed with stars. Are these really openings where we look through between the swarms of stars into dark regions beyond, or are there intervening dark masses, black nebulæ that cut off the light of stars that are uniformly distributed? This is a question which astronomers are discussing, and some are inclined to belief in the existence of such dark masses of matter.

I said a little while ago that the white background of the picture taken with the 2½-inch camera was not due to nebulous light. From this it must not be thought that none of the Milky Way is nebulous. In many of the photographs we have found distinct evidence of great masses of very faint nebula in the galaxy, so faint it can never be seen with a telescope because of its diffuseness and cannot be distinguished with the naked eye because of the sky-light. Indeed, it is only on the most transparent nights that we can prevent the sky-light from obliterating this nebulosity on the photographic plate.

From what has been said and the comparison of these three plates presented, it may be judged correctly that, even from such an impersonal agent as the photographic plate, we cannot expect uniformity nor absolute accuracy of results in depicting the structures of the heavens. Personality cannot be divorced from the making of the apparatus, the preparation of the sensitive plate, its exposure and development. Yet, notwithstanding these impossibilities, I think we may safely say that this process is far ahead of the eye and hand method, and that in a few years we may have reasonably perfect representations of that wondrous zone of light that nightly challenges our admiration and wonder.

Let no one think that it is easy work. I know of no astronomical work that is more tedious than sitting almost motionless at the eye-piece of a telescope hour after hour, trying to prevent the escape of a little point of light from the intersection of two cross-threads of spider-web. Then, when, after many hours of watching and waiting, the observer on developing his plate finds that something has slipped, so that the stars are all double, or that the plate has a great flaw in the middle, it is a matter of great discouragement. On the other hand, when all goes right and the observer finds that he has a picture of the highest excellence, of real scientific value, the satisfaction pays for all the trouble.

THE FIXED STARS.—VI.

W. H. S. MONCK, Dublin, Ireland.

For Popular Astronomy.

According to the principles of the wave theory of light, which I think may be regarded as proved, waves or undulations in the ether are propagated through space with a velocity of about 186,000 miles per second. The velocity of the Earth or of any

known star is very small compared with this; still it is large enough to produce the well-known phenomenon called the Aberration of light, which I need not here describe. The color of light depends on the number of undulations which fall on the eye in a second. If a star is approaching us the number of undulations which fall on the eye in a given time will be increased and if receding from us the number will be diminished. Increasing the number of undulations will render visible a little strip of the spectrum just beyond the red end and render invisible a little strip of the violet light at the other extremity. If the star is receding from us this state of things will be reversed. But of course no quickening or slowing of the undulations will affect a ray that is missing owing to its absorption by the star's atmosphere. Hence the fixed lines will remain where they were. But the addition of a little strip at the red end and the cutting off of a little strip at the violet end will make the fixed lines *appear* to be nearer to the violet end and more distant from the red end than before. Consequently if a star is approaching us the fixed lines will appear to have shifted towards the blue end of the spectrum, while if it is receding from us they will appear to have shifted towards the red. And it has been found practicable by measuring the amount of the displacement to compute the velocity with which the star is approaching or receding. This, however, is a very difficult task. The stellar spectra are usually very faint and very unsteady and the quantities to be measured are so small that a trifling error in the measurement may actually reverse the real motion of the star. Moreover the lines in the spectra of some stars are thicker than in others and in trying to measure the middle point of a thick line many causes of error may arise. Some time ago, however, Vogel found that measurements could be made much more accurately on a photograph of the spectrum than on the spectrum itself. His results exhibited a natural agreement which seemed to indicate that they were not very far from the truth: and his table of the velocities of approach or retrogression in the case of about fifty stars is undoubtedly the most reliable that we at present possess. They do not exhibit the very high velocities which some other observers deduced from spectroscopic observations. The average is little over ten miles per second, the fastest (Aldebaran) moving in this direction at about three times that rate. This of course gives us the velocity in only one of three directions mutually at right angles to each other. Motions in the other two directions are given by the proper motion as already described. The one velocity, however, is given in miles per

second of time—the other two in seconds or fractions of a second per annum on the celestial sphere. It is not unnatural to assume that on taking the average of a large number of stars the motions in these three directions will be about equal, and we can thus make a rough estimate of the average distances of a number of stars whose proper motions are known. Taking the average annual motion in declination of a star of the second magnitude for instance, we may assume that it represents a motion of ten miles per second and compute the average distance of these stars accordingly. One important consequence seems to follow from the researches of Vogel, though it would no doubt be desirable to try more than fifty stars before arriving at any positive conclusion, viz: that there is no material difference in the actual velocity with which Sirian and solar stars are moving through space. Hence the greater proper motions of the solar stars means that they are nearer to us than the Sirians of the same magnitude. Of course the velocities of the stars in the line of sight as well as their proper motions measured on the celestial sphere are affected by the motions of the solar system through space; and no direction can be assigned to the Sun's motion which would account for them all. Attempts to determine the apex of the Sun's way—or as it is more briefly termed the Sun's goal—by means of these spectroscopic velocities have been made, but the results are not altogether satisfactory. Judging from the velocities of the stars in Vogel's list we are moving towards a point in the northern hemisphere whose declination does not differ much from that obtained by other methods but whose right ascension seems to be considerably less. Owing to the comparatively small number of stars whose velocities in the line of sight have hitherto been ascertained, however, the position derived from the proper motions of the stars is probably more nearly correct. Another question which will no doubt be solved ere very long by observing the velocities of the stars in the line of sight is whether the fainter or more distant stars are really moving with greater velocity (on the average) than the brighter and nearer ones? The proper motions of the stars do not diminish with the intensity of their light (*i. e.* with their magnitudes) as rapidly as theory would lead us to expect. This seems to indicate either greater absolute velocity in the case of the more distant stars or else an absorption of light in the intervening space. But if no greater absolute velocity is detected by the spectroscope we may abandon the former of these hypotheses. Hitherto, however, it is only in the case of the brighter stars that reliable velocities have been

ascertained and the comparison in question cannot therefore be made.

It should not be forgotten that dark lines belonging to different elements sometimes lie very near each other and a mistake as to which line is observed might lead to a serious error as regards velocity. Lines too seem to be affected by other causes. One of these is probably the pressure or density of the gas. Again the rotation of the star may have a similar effect. In the surface which a rotating star presents to us, part is probably moving towards us and part away from us in consequence of the rotation and the line will thus appear broader than it really is since the incident light is really travelling with different velocities. A good deal of the controversy as to the Meteoritic Hypothesis turns on the exact position of certain lines in the stellar spectra; and we are hardly in a position to say that every shifting of a line in the spectrum is due to velocity in the line of sight. The results derived from the New Star in Andromeda are rather startling if due to changes of velocity only. Considerations of this kind tend to diminish our confidence in any derivation of the direction and velocity of the motion of the solar system from spectroscopic velocities at present. There is no doubt, however, that the spectroscopic method will ultimately prove the best for the ascertainment of its *velocity*. We cannot (in the absence of a large number of reliable determinations of parallax) infer the velocity of the Sun's motion from the proper motions of the stars without making assumptions as to the distances (or at least the average distances) of these stars which can hardly be regarded as more than mere conjectures. Indeed they have hitherto proceeded on the assumption that the average distances vary with the magnitudes of the stars, overlooking the great distinction between Sirian and solar stars as well as their sub-classes: or else on the assumption of a relation between distance and proper motion which is far from being fully established. And even if it were legitimate to assume that stars with a proper motion of 0″.2 per annum are on the average only half as distant as stars with a proper motion of 0″.1, who is to tell us what the average distance of either of these classes of stars is?—without which we cannot reduce their velocities to miles per second. It is indeed this measurement of spectroscopic velocities in the line of sight that affords the principal clue for comparing terrestrial distances with distances in the stellar regions. The velocities appear as a rule to be commensurable with those which we observe within the limits of the solar system.

But the spectroscope has revealed many other facts in Stellar Astronomy, one of the most remarkable being the discovery of double stars which are too close together to be separated by any existing telescope or any telescope that we are likely to possess hereafter. The discovery turns on the following principle. In the case of a binary star both stars revolve round their common centre of gravity. The Sun is so large compared with the planets that its motion in accordance with this law is almost imperceptible, but with some of the fixed stars the pair seem to be almost equal in magnitude and in all cases the smaller star seems to be larger compared with its companion than Jupiter when compared with the Sun. Otherwise indeed its existence would rarely if ever be detected. Now suppose that the plane of the orbit of such a binary pair passes nearly through the Earth, it is evident that each of the pair in describing its orbit will at one time be approaching us and at another time receding—one star being farthest off when the other is nearest to us and *vice versa*. Two cases may here occur. Both stars may have spectra capable of affecting our spectroscopes but which owing to the closeness of the stars are usually superposed on each other: or the spectrum of one star only may be visible, that of the other being too faint for the spectroscope which we are using.

The discovery was first made with a pair of the latter kind. The star Algol (β Persei) had long been known as a variable star and it was noticed that the variations of its light strongly resembled the phenomena of an eclipse of the bright star by a dark body of somewhat less magnitude. The diminution of light returned with the regularity of clock-work and the amount of diminution was always nearly the same—about one magnitude, involving a reduction of the light by about 60 per cent. But if this change was caused by an eclipsing body the latter was of course nearest to us at the time of the eclipse. Consequently the bright star was farthest off at that time and must have been receding from us before the minimum—the middle point of the eclipse—and began to approach us immediately after. Observations were made by Mr. Maunder at Greenwich with a view of testing this question, but the result was not very satisfactory. Vogel then took up the problem by the aid of photographs of the spectrum, and his researches placed the existence of the eclipsing body beyond doubt. Fortunately the pair considered as a system had but little motion in the line of sight and the orbital motion was thus the most prominent item in the spectroscopic results. The bright star was clearly receding from us before the minimum and approaching us after it.

This discovery was followed not long afterwards by a similar one in the case of Spica (α Virginis) where however there is no actual eclipse and no variation in the light. But Spica instead of the steady approach or steady recess indicated by the majority of the stars was clearly approaching and receding from us alternately with a period of about four days. Evidently there is a dark companion which must very nearly eclipse the bright star at some part of its course but the actual eclipse is avoided. There are, however, some eight or ten known stars whose light varies in the same manner as that of Algol and which therefore may fairly be assumed to be eclipse-stars though accurate spectroscopic results are not easy to obtain owing to their faintness. In one of these the period of revolution is less than a day. These eclipse-stars, as far as hitherto examined, appear to have spectra of the Sirian type and they seem to be the only Sirian stars whose light is variable. No doubt owing to their own motion and that of the Sun through space the eclipses will ultimately cease and their condition will resemble that of Spica. The latter star has probably either been an eclipse-variable in the past or will become such in the future. The phenomena which these stars present are quite unlike those of other variable stars.

The discovery of spectroscopic double stars where both were bright was made at Harvard Observatory by Professor E. C. Pickering. When one star is farthest from us and the other nearest to us the orbital motion to or from the Earth may be regarded as nil. Hence the dark lines in the spectra of the two stars will be superposed. But as one star moves away from us in its orbit while the other is approaching us the lines will widen out and ultimately separate into two. Periodical separation and closing up again of the dark lines of the spectrum of what is apparently a single star thus indicates that it is really a close binary revolving either in the period or in double the period that elapses between two of the widest separations (such a separation may take place twice or only once during a revolution according to the nature of the orbit and the angle at which it is presented to the eye). An actual passage of one of these stars across the face of the other would no doubt cause a diminution of light, but this has not hitherto been observed. Nevertheless Professor Pickering feels confident that the well-known stars Mizar (ζ Ursæ Majoris) and β Aurigæ are close double stars whose constitution is revealed by the periodical separation and closing up again of the lines in their spectra. He moreover indicates another mode in which double stars may be detected by the spectroscope. If the

two components have spectra of different kinds—Sirian and solar for example—the compound character of the spectrum would probably be noticed as soon as a good classification of spectra was established. He suspects the existence of this cause in more than one instance where the star presents a peculiar spectrum, but does not seem as yet able to affirm it positively.

With the exception of Mizar, which has a period of either 52 or 104 days, all spectroscopic doubles hitherto detected appear to have very short periods and on the modern theory of tidal friction the binary system is probably at an early stage of its formation. The stars as already remarked seem to be of the Sirian type and some plausibility is thus added to the conjecture that this type of spectrum indicates an early stage of star-history. The duration of the eclipses compared with the total period of revolution moreover seems to indicate a low density in both bodies. It has indeed been conjectured that in some cases the obscuration is due to a dense flight of meteors rather than to a single star. It has been maintained that Saturn's rings consist of such meteor-flights though I hardly think the meteors could be so uniformly distributed over every portion of their orbits as to give rise to the appearance of these rings. But such rings would not explain the phenomena with which we are now dealing unless their number and position relative to the axis of the rotation of the star differed much from what we experience in the case of Saturn. A meteor-flight containing a sufficient number of meteors to darken the star perceptibly for some hours should I think consist of meteors whose periods differed from each other sufficiently to break up the groups within a short time and render the darkening of the star pretty nearly uniform at all times. The inner portion of the flight would gain upon the outer portion. The light would be diminished for a longer and longer period on each return but the minimum would become less marked. No such progressive change appears to have been observed. The small density of these stars therefore probably arises from other causes of which the most probable is that, taking the photosphere as defining the limits of the star, a larger proportion of the included matter is gaseous and a smaller proportion solid or fluid in the Sirian than in the solar stars. The photosphere of the Sun as a star probably resembles most closely a luminous cloud or stratum of luminous clouds. In the case of Sirian stars we may suppose the light to come from high level clouds and in that of solar stars from clouds at lower levels. At the ultimate stage (if we suppose a continuous cooling) the light would probably come from the

solid or fluid surface of the star; but the light of a star at this stage might perhaps be so reduced as to render it invisible with our present telescopes unless it approached us more closely than any known star. Indeed the surface might not improbably be covered with dense masses of opaque clouds which would cut off the light altogether and would not condense until the surface sunk below a red heat. This was probably at one time the state of our earth. The phenomena of Sun-spots as well as the low specific gravity of the Sun seem to indicate that a good part of what lies within the photosphere is gaseous, but to convert the Sun into a Sirian star the photosphere might have to be moved out to the limits of the corona. This will probably be found to be the explanation of the respective characteristics of the spectra of solar and Sirian stars respectively. In the Sirian spectrum we find only the lines of the lighter and finer gases which if the star was cooling would be the last to condense while in the solar spectrum we find the lines of refractory metals like iron which only vaporize at a very high temperature. Hence we might be disposed to infer that the solar stars were the hotter of the two and that a solar star became a Sirian in the process of cooling by the condensation of the metallic vapors and the consequent disappearance of their lines from the spectrum. This inference would be natural enough if the photosphere was the solid or fluid body of the star; but when we assimilate it to a cloud we see at once that if the cloud is formed at a very high level we can only expect to find the lighter and finer gases above it and that as this luminous cloud sinks in the stellar atmosphere the lines belonging to other gases will appear. Nevertheless it should be borne in mind that if cooling proceeds there will be a final stage at which the metallic lens will disappear in consequence of the condensation of the metallic vapors and the lines of the lighter and finer gases will again become the predominating feature of the spectrum. And it is to this cause that I should be disposed to attribute the resemblance that exists between the spectra of the Sirian and Capellan stars—the former being brighter and hotter and the latter duller and colder than the stars of the Arcturian type in whose spectra the metallic lines are more numerous and strongly pronounced than in either. My readers will of course recollect that speculations of this kind must be carefully distinguished from ascertained facts—a distinction which has often been insufficiently observed by writers on popular astronomy.

THE SPECTROSCOPE IN RECENT CHEMISTRY.

R. A. GREGORY.

FROM THE FORTNIGHTLY REVIEW.

It may be taken as a rule, to which there are few exceptions, that great scientific discoveries are not made by intending the mind upon them; they do not come as the result of one man of science saying to another, "Go to, let us make this or that discovery," but are rather the unexpected conclusions deduced from facts accumulated with no other end in view than the extension of natural knowledge. Whither an investigation will lead, the man of science knows not. His the task to explore the realm of nature, and no divine guidance is vouchsafed to him, whereby he can pierce the darkness and catch a sight of the scene beyond. But whatever road he takes is a road to knowledge, and though, after devoting the labors of a lifetime to a research, he may find that the same amount of progress could have been made by a much shorter route, he has the satisfaction of knowing that on his way he opened up many new fields of inquiry.

The scientific investigator is an explorer of nature's domain; he is, perhaps, better compared to a detective, for his methods of work are precisely the same. The crimes upon which he is engaged are natural phenomena, and by following up one clue after another, he aims at discovering the causes which produce them. As in the case of the detective of fiction, nothing must escape his observation; he carefully examines everything connected with the case he has in hand, and then forms a theory as to how and by whom the deed was accomplished. Suspicion sometimes falls upon some innocent forces or molecules, and circumstantial evidence may be so convincing that they are convicted and their guilt is proclaimed to the scientific world, but such cases form only a very small proportion of the whole. Two recent discoveries in chemistry bear out the analogy. That eminent detective in chemistry, Cavendish, lighted upon traces of a new constituent of the atmosphere, but he did not inquire into the cause of them. A century passed before this clue was followed up, and found to point to a stranger among the known elements in our aerial envelope. After considerable difficulty, the offender was caught, confined and labelled; and under the exciting influence of electric shocks, it was made to disport itself before an admiring public at scientific soirées and conversaziones. The capture of this strange gas from the air led to the identification of a solar ele-

ment that had been wanted on the Earth for a quarter of a century. This gas was literally "run to Earth;" and like its companion, it was placed in solitary confinement for the exhibition of its peculiarities to the curious. Naturally the scientific world was excited at the successful capture of two individuals that had escaped detection for so long, and since the prisoners have been in custody facts have come out which have greatly increased the interest in them. Chemists were, certainly, a little disconcerted that they should so persistently have overlooked one of the components of the air, but their embarrassment is to some extent relieved by the knowledge that the astronomical spectroscopist failed to recognize a gas which is now known to be easily and copiously obtainable from fairly common minerals, though he had probably met with it in the laboratory scores of times. The physicist has also been brought to see the depths of his ignorance on some points connected with the kinetic theory of gases, so that the whole world of physical science has been disturbed by the imprisonment and characteristics of the two gaseous prisoners lately arrested.

If the whole history of science be searched, probably no better examples of two widely different ways to scientific discovery could be found than is afforded by the researches which have recently led to the discovery of argon, and the identification of helium. The demonstration of a new constituent in the Earth's atmosphere, and the conclusion that this component—argon—must be added to the list of seventy odd elements, is a veritable triumph for experimental philosophy, obtained only after many years of what may truly be termed tantalizing work. With helium the case was very different. An experiment, conducted with one end in view, led to a chance observarion of the highest significance. Quite unintentionally, a discovery was made even more valuable to astronomical science than the isolation of argon seems likely to be to chemistry. This, as well as the difference between the two investigations, will be more clearly seen after a statement of the circumstances attached to each case.

For a number of years Lord Rayleigh, one of the secretaries of the Royal Society, has been making experiments to determine, with the utmost degree of accuracy, the densities of nitrogen and other gases. The point eventually brought out by his researches was, that nitrogen extracted from the atmosphere was about one-half per cent heavier than nitrogen obtained from various chemical compounds. It was first thought that the difference

might be caused by contamination with common impurities; that in fact, an ingredient specifically heavier than nitrogen was mixed with the gas derived from air, or one lighter, hydrogen, for example, was blended with nitrogen made from compounds. Not for an instant was it supposed, in the earlier stages of the work, that any new substance was the cause of the discrepancy, and especially was it considered improbable that the greater density of the atmospheric nitrogen was due to the presence of an unknown constituent of air. For it was hardly thinkable that a gas, which is now known to surround us in enormous quantities on all sides, could have escaped detection in the thousands of analyses to which chemists have subjected our aerial envelope, in all sorts of places and under all kinds of conditions. Such, however, were the facts, and so great is the reliance placed upon Lord Rayleigh's work, that no physicists thought of questioning the accuracy of his results, however much they might be at variance with the observations of chemists. After the definitive results had been published, and after the discrepancy between the weights of equal bulks of atmospheric and chemical nitrogen had been talked over in scientific circles, Professor Ramsay joined with Lord Rayleigh in the endeavor to discover the cause of the anomaly. Following up the indications of the experiments, both workers extracted nitrogen gas from air, and then endeavored to eliminate it, in order to see if a residue composed of any other gas would be left. Both were successful in detecting and isolating the unknown and heavier constituents, though by different methods. The existence of a gas new to science was proved by many lines of evidence, and the abnormal density of atmospheric nitrogen was shown to be due to the presence of this body in air. Into the questions of the chemical nature of the gas it is not now proposed to enter. The story of the discovery is briefly told in illustration of the patient work and tedious experimentation that had to be carried out, before the teaching of the results came to be understood.

The reality of argon having been established, evidently the next thing to do was to examine, so far as possible, the nitrogen from different sources, to see whether it was nitrogen mixed with argon or with argon compounds. In the furtherance of this research for chemical combinations of argon, Professor Ramsay was led to experiment upon cleveite, a rare Norwegian mineral, which had been found to give off, when boiled with weak sulphuric acid, two per cent of a gas supposed to be nitrogen. The question to be decided was: "Did this gas contain any argon, either free or com-

bined?" Never was an inquiry answered in a more definite manner than by Professor Ramsay's experiments. The gas proved to contain only a trace of nitrogen. To determine readily the character of the remainder, some of it was sealed up in a glass tube, through which an electric current was passed—this being the usual method of making a gas luminous, so that the quality of its light can be observed by means of the spectroscope. The light passed into this marvellous instrument of research, and was sifted into its component parts by the prism. And when the bright lines into which it was resolved were observed, they were found to comprise a number of prominent rays of which the origin was not known; in other words, the gas which had been believed to be nitrogen was something quite different. One of these bright rays was especially brilliant. At first sight it seemed to be the badge of sodium—and it might well have been passed as such, for the spectroscopist expects to find sodium in everything, and the line seen occupies very nearly the place of a sodium ray in the light scale. To settle the matter, Professor Ramsay sent a tube, filled with the gas, to Mr. Crookes, who undertook to make a full spectroscopic study of its contents. Mr. Crookes possesses a powerful spectroscope, and, like all experienced workers with this instument, he knows by heart the collections of lines into which the prism breaks up the light from different luminous gases and vapors. Upon electrically illuminating the gaseous contents of the tube, he saw the bright yellow line, apparently occupying the place of sodium in the spectrum. Two tests, however, proved that this ubiquitous element was not being observed. When viewed with a fairly powerful spectroscope, the sodium badge, which looks like a single bright line in an instrument having small capacity for dispersing light, is seen to consist of two lines very close together. But observation showed that the conspicuous band of yellow light was not a twin-line at all; it remained rigorously single whatever power was brought to bear upon it. To clinch the matter, sodium light was thrown into the spectroscope simultaneously with the light from the new gas, and the two sources of luminosity were then found to be of two distinct qualities. The pair of sodium lines were observed in their customary positions, and a very little higher up in the light-scale the strange line found a place.

The line seen in the light of gas from cleveite was strange to terrestrial laboratories, but not new to spectroscopic science; it was identified as a line belonging to helium, an element only previously observed in analyses of solar light. This was a discovery,

the full significance of which can only be appreciated by workers in solar physics. To astronomers it is just as important as the isolation of argon is to chemists, though it was arrived at much less laboriously. Not a man of science, but would be content to spend many years of work to achieve the result, yet by simply adding weak oil of vitriol to cleveite and investigating with the spectroscope the gas evolved, it was possible to prove the existence of terrestrial helium. It is not, perhaps, too much to believe that spectroscopists had observed the spectrum of this element in their laboratories before; but either for want of time and efficient instruments, or because they lacked perspicacity, they did not appreciate the strangeness of the view, and so missed a remarkable discovery well within their reach.

The brilliant line now identified has been observed in solar phenomena for more than a quarter of a century. During the total solar eclipse of 1868, the spectroscope showed that the red flames or prominences visible here and there around the Sun's edge, when the dark body of the Moon had cut off the dazzling light of the Sun's visible surface, consisted of luminous gases, chief among which was hydrogen. Shortly afterwards, Mr. Norman Lockyer perfected his method of observing solar prominences at any time when the Sun is shining; and he then found that, in addition to hydrogen, the light of these tremendous flames commonly exhibited in the spectroscope a yellow line, which had no counterpart among the dark lines seen when ordinary sunlight is analyzed; nor could any terrestrial substance be found to emit radiations of the same quality. The conclusion indicated by the observations was, that the substance which emitted the enigmatical light was the exclusive possession of bodies at the intense temperature of the Sun, and for this reason Professor Lockyer gave it the name helium—the element of the Sun. For twenty-six years, solar observers have watched the helium line, and have wondered at its mysterious extra-terrestrial character. It is now known that the name is a misnomer. The position, in the light scale, of the line from cleveite gas, has been found to agree with that of the line due to the hypothetical element, helium. To establish the identity beyond the possibility of a doubt, a direct comparison of the cleveite line with the helium line has been made. To do this, a tube containing the new gas was electrically illuminated, and so arranged that its light could be seen in a spectroscope at the same time as the light from a solar prominence containing helium. As, under these conditions, the two lines appeared to be identical in position, the discovery seems almost established beyond all question.

There are, however, dissentients from this view. Professor Runge, a well known and trustworthy worker with the spectroscope, has given reasons for believing that the conclusion has been arrived at a little too hastily. An examination of the terrestrial gas has shown him that the conspicuous yellow line it bears is double; therefore, he argues, and with some force, that it cannot be identical with helium proper, unless the characteristic line of that solar element is also shown to be double, and with the two components in the same position on the light scale as those measured by him in the laboratory. Dr. Huggins has since examined the solar line and finds it to be rigorously single, so the difference remains to be explained. It is just possible that, assuming the difference pointed out by Professor Runge to be established, the duplex character of the yellow badge of terrestrial helium is due to the gas being observed under conditions different from those which obtain on the Sun. Fortunately, the case for the identity of the gas from cleveite with helium gas, does not depend entirely upon the coincidence of the solar spectrum-line with a line observable in the laboratory. Five or six characteristic rays of terrestrial helium have been proved by Professor Lockyer to match bright lines which appear most frequently in the analyzed light of solar prominences. Dr. Deslandres, of the Paris Observatory, finds the same agreement in the light of terrestrial and solar material, so there seems little room for scepticism in the matter.

It may be thought that the identification of another terrestrial element in the Sun, or rather the existence of another solar substance on the Earth, is not a matter of the highest importance. But helium is not as other elements are; it is unique in many ways; it is a characteristic component of that tempest-tossed sea of luminosity—the solar chromosphere—out of which the prominences spurt and spout, now rising in jets for thousands of miles, and anon hanging for hours or days together in fantastic forms over the turbulent stratum from which they rise. Evidence has been brought forward that at the great temperature of the Sun, bodies we regard as elements are broken up, or dissociated, into more elementary forms of matter; and it has been suggested that helium is the primordial substance into which all elements can be resolved by proper means. Chemists, generally, regard the theory with disfavor, and stamp as heretics those who give it consideration. But now that helium has been found on the Earth, we are within reasonable reach of some further inquiry on the subject.

The promise of the future in regard to knowledge of the nature

and properties of helium is not likely to be an empty one, for the gas has already been found in from fifteen to twenty different minerals, though not associated with argon, which has never yet been obtained from minerals. But, though argon has not a mineral source, helium is so easily enticed from its seclusion that workers with the spectroscope are a trifle depressed at its belated discovery. As a matter of fact, spectroscopists have in recent years confined their attention too exclusively to problems in celestial chemistry, and have somewhat neglected the spectroscopy of the common substances which form the Earth's crust; if this were not the case, argon and helium would have been discovered long ago. But a new era has now commenced, and the spectroscope will take a more prominent place in chemical analysis of the future than it has in the past.

The two new gases have already furnished astronomy with a number of valuable facts. Shortly after the discovery of argon had been proclaimed, some one pointed out that a strong line in its spectrum occupied about the same position as the ray which characterizes the light of the misty material of which nebulæ are composed. Little attention need be paid, however, to this accidental, and not very close, coincidence. A single swallow does not make a summer, nor is the coincidence of one of the many lines in the spectrum of argon, with a line in nebular spectra, sufficient to base any argument upon, even if the terrestrial and celestial rays exactly correspond with one another. A more important fact is that lines due to helium are undoubtedly found among those into which the light of nebulæ is broken up by the prism. And Professor Lockyer has carried the matter still further in an astronomical direction, by comparing the spectra of the gases (consisting chiefly of helium) obtained from various minerals, with the spectra of certain stars.

It is now commonly known that the chemical constitution of the atmosphere of a star can be determined by means of the spectroscope, which breaks up the composite stellar beams into the component parts, and presents to the observer a faint strip of light usually crossed transversely by dark lines. These sombre rays are the tongues of elements which make up a star's gaseous envelope, and astronomers have long been engaged in finding terrestrial interpreters of their languages. One after another substances on the Earth have had their spectra brought side by side with analyzed starlight, with the result that many stellar rays have been found to have terrestrial equivalents. But much still remains to be done; the Sun is a star which can be studied under

the best conditions, yet the origins of about two-thirds of its spectrum-lines still remain a mystery, while, in the case of the more distant Suns distributed through interstellar space, the satisfaction at the information which the spectroscope has drawn from them concerning their constitution is greatly impaired by the knowledge that so much remains a mystery.

Professor Lockyer's comparison of star-spectra with the spectra of the new gases obtained by heating various minerals in a vacuum, has enabled him to reduce the number of enigmatical rays in starlight. He has found that the lines due to helium are exactly matched by lines in the spectra of a certain type of stars, as well as by lines in the solar chromosphere, and has thus been able to demonstrate a relation between the new gases and solar and stellar phenomena. His conclusion as to the results which are likely to follow from this, is very sanguine. In a paper recently read before the Royal Society, he said: "We appear to be in presence of the *vera causa*, not of two or three, but of many of the lines which, so far, have been classed as 'unknown' by students, both of solar and stellar chemistry; and, if this be confirmed, we are evidently in the presence of a new order of gases of the highest importance to celestial chemistry, though, perhaps, they may be of small value to chemists, because their compounds and associated elements are, for the most part, hidden deep in the Earth's interior." The thought expressed in the latter part of the quotation is a very suggestive one, and it indicates the reason why the state of knowledge of the chemistry of the Sun and stars remains so imperfect. It is known with some degree of completeness how far the common elements upon the Earth are found in stars, but of the gases which, in all probability, are occluded in the heavier minerals, we are only just beginning to acquire information, though *á priori* considerations point to them for the solution of many extra-terrestrial spectroscopic phenomena. No wonder, then, that Professor Lockyer regards the future study of the actions and reactions of the new order of gases as full of promise of a terrestrial chemistry of paramount importance in connection with questions of stellar evolution. So many facts seem to justify this hope, that it is almost a pity to say anything which will diminish the satisfaction derived by spectroscopists from contemplation of the new vista. It is just as well to bear in mind, however, that there are limits to the possibilities of spectroscopy. We know, for instance, that solar prominences, and the sea of flame from which they rise, are largely composed of helium; of that there is no doubt whatever, nevertheless, if

the Sun could be taken away into space until it had dwindled into a star, the spectroscope would fail then to reveal the existence of helium, though the constitution of the Sun had not altered a jot. Even though most stars fail to show helium in the spectroscope, this is no proof that helium is absent from them, and the same reasoning can be applied to other elements.

There are other reasons for regarding as incomplete the knowledge gained by the spectroscope as to the constitution of the Sun and stars, or as affording evidence of the presence of a particular gas in a gaseous mixture. Recent experiments have shown Professor Ramsay that if a small proportion of nitrogen or hydrogen be introduced into a vessel containing argon or helium, the characteristic spectra of the two latter gases are completely masked, that is to say, if only spectroscopic evidence were relied upon, the verdict would be that neither argon nor helium were present in the mixture. Indeed, quantitative experiments have brought out the astonishing fact that from five to ten per cent of nitrogen entirely obscures the characteristic yellow line of helium. Probably the laboratory conditions differ from those of the Sun, but if they were the same we should have to conclude that a small percentage of nitrogen in the Sun's chromosphere would have prevented us from ever seeing helium. Spectroscopic astronomers have reason to be proud of the achievements of their instruments of research, but the consideration of such facts as those referred to will show them that what is known may be as nothing compared with what is not known about the chemical constitution of celestial bodies.

The testimony afforded by the spectroscope as to the nature of celestial things is, therefore, imperfect. In pre-spectroscopic times, meteorites were the messengers which gave the world a faint conception of extra-terrestrial matter. The mode of origin of these objects is not exactly understood, but they are generally regarded as fragmentary products of eruptions on the Sun, stars, or planets. But leaving the question of origin at present out of consideration, it is evident that meteorites should be able to assist in correlating terrestrial and celestial chemistry. An examination of "holy things fallen from heaven" furnished Professor Lockyer with the foundation upon which he built his meteoritic hypothesis a few years ago, and Professor Ramsay has now greatly added to the interest attached to those masses of iron and stony matter, for he has found both argon and helium in a meteorite which fell at Augusta County, Virginia. A few ounces of the meteorite were placed in a glass tube and heated. The gas

driven off proved for the most part to be hydrogen, but after subtracting this and other well-known gases, the residue was found, by spectroscopic examination, to consist of the two new gases which have created such a sensation in scientific circles. Argon and helium have thus been proved to be contained in meteoritic matter, and the question naturally arises: How did they get there? Professor Ramsay suggests that the meteorite was once part of a stellar body at a high temperature, having an atmosphere in which hydrogen, argon, and helium existed, with other gases. In this atmosphere the mass was heated to fusion, to be finally ejected by some volcanic force. But plausible as this explanation is, it must remain only an unconfirmed theory, for, in the first place, it is possible, though very improbable, that the meteorite was ejected by a terrestrial volcano; and, secondly, there is not sufficient evidence that the meteorite could not have derived its argon from the Earth's atmosphere, and the small proportion of its helium from the upper limits of the atmosphere. Assuming the theory to be true, the meteorite affords direct evidence of the existence of argon and helium in stellar atmospheres.

Helium has not yet been found in the air, nor is it likely to be. As with hydrogen, its atoms are so light that the Earth is unable to hold them, and their energy is sufficient to carry them eventually outside the sphere of influence of our globe. This brings us to a very important point raised by investigations of the energy of argon and helium atoms. The molecules of every gas are known to be dashing about in all directions, with a velocity depending upon the temperature. When a gas is heated, these motions are increased, so that a rise of temperature means an increase of the energy of the molecules. Now the amount of heat expended upon the gas can be expressed in terms of energy, for heat is a form of energy; and the energy used up in making the molecules travel faster and further can be found by observing the rise of temperature, when the gas is enclosed in a vessel, and when it is allowed to expand. Accurate experiments show that the energy supplied is not all accounted for by the measurable effects produced. Some of it is apparently used up in giving relative motion to the different parts of the molecule, which may consist of one or more atoms. To some extent the energy thus used internally depends upon the number of atoms in a molecule, therefore measurements of the amount of this energy give a clue to the constitution of gaseous molecules. Now, in the case of argon and helium, and also in that of mercury vapor, the energy

absorbed by atomic motions is extremely small—practically, all the energy supplied is taken up by the increased motions of the molecules. The conclusion drawn from this is, that, in these gases, the atom and the molecule are synonymous, or, in scientific terms, that they are monatomic gases. So far all is plain sailing, but when the spectra of such gases come to be considered, the theory is found wanting. According to one view, the luminosity of a gas through which an electric current is passing is due to the vibrations of the atoms in the molecule, so that a monatomic gas could not be made luminous, and therefore could have no spectrum. This theory is at once confuted by the fact that mercury vapor, argon, and helium can be made luminous, and all three have characteristic spectra. As a matter of fact, the theory upon which the case for the monatomicity of these elements rests leaves the optical properties out of count. The most feasible view seems to be that the luminosity of a gas through which an electric current is passing, and, therefore, the spectrum of the gas, is due to vibrations of the hypothetical ether surrounding the molecules, and not to the vibrations of the molecules themselves. If this be so, it should be possible to deduce the phenomena of spectroscopy from the electro-magnetic theory of light, now accepted by physicists. This theory to account for the spectra of gases has yet to pass through the fire of criticism, and one of the first points it has to answer is how different gaseous molecules cause the ether to vibrate differently. But whether this theory is compatible with facts or not need not be discussed here; at any rate, argon and helium have raised some very nice points over which chemists, mathematicians, and physicists may wrangle for some time to come.

One other point remains to be mentioned. Two lines in the spectrum of argon appear to be exactly coincident with two in the spectrum of helium. This and other considerations indicate that argon and helium contain, as some common constituent, a gas not yet isolated. Professor Ramsay regards the presence of the third new gas as almost certain, and Professor Lockyer hints at the existence of several more. Surely more startling statements were never before precipitated upon the world of science. But whatever results future work may lead to, it can already be said, without fear of contradiction, that since spectrum analysis became an accomplished fact, no new elements have held out greater promise of assistance in unravelling mysteries of celestial constitutions than argon and helium, and the gases which are associated with them.—*Littell's Living Age, No. 2671.*

HOW THE TELESCOPE AIDS ORDINARY VISION.

W. W. PAYNE.

FOR POPULAR ASTRONOMY.

So many questions are asked by intelligent readers about the magnifying powers of telescopes, that it seems best to mention the important facts relating to this theme so well known and so useful to the practical astronomer.

For our present purpose all we need to notice about the telescope is its object-glass and its eyepieces. The use of the object-glass is primarily two-fold, viz: to collect the parallel rays of light from a distant object that fall on its outer surface, and to focus those rays in a small but well-defined image at a distance from the object-glass called its focal distance. The image of the celestial object thus formed will be bright in proportion to the amount of light which the object-glass is able to gather and transmit to it. Object-glasses of the same size may have different focal lengths and still be excellent in quality, but those having the greater focal length will form the greater focal image.

A man much interested in all recent astronomy said to us the other day, "If light is one of the things you want why not use electric light and put abundance of it on the image and then use still higher magnifying power and so tell us more about the planets." Most of our readers will readily understand that the astronomer is not favored in this way as the microscopist is. He has not the privilege of so illuminating the *object* whose *image* he is studying as may be done often in the use of the microscope. Generally the astronomer can use only the light that comes directly from the heavenly body, and he must plan to get as large a quantity of it as possible, and then cause that light to fall on the image at the focus that it may be greatly increased in size by the eye-piece and still be bright enough to be seen well. Astronomers are now trying curious devices in order to gather more light from the heavenly bodies so as to reach the end suggested above in a way that will be in keeping with common laws of physics.

The use of the eyepiece is to magnify the image formed by the object-glass and make rays of light from it sensibly parallel as the normal eye can use such a beam of light for distinct vision. The different kinds of eye-pieces in ordinary use accomplish this in different ways which are adapted to the kind of work the astronomer is trying to do. If he is trying to measure the distance between two stars he may need a flat field, as it is called, then he

will use an eyepiece like an ordinary hand magnifier which he calls a *positive* eyepiece because the image viewed by it is outside of itself. If the observer is making a careful study of the surface details of a planet, for example, he will then use another kind of eyepiece which is called *negative*, because the image from the objective is formed between the two lenses of the eyepiece that are usually separated from one another an inch or less. The positive eyepiece gives a flat field of view, but brings into it some color that does not belong to the object under study. This is the weak point in this kind of eyepiece, and because of this astronomers say it is not *acromatic*. The negative eyepiece is better in this regard, but it is not perfectly acromatic. So the observer must be on his guard in original observations that the slight imperfections of his instrument do not mislead him when he is trying to determine shades of color belonging to various celestial objects.

It is not our purpose now, to show how the object-glass and the eyepiece of a telescope take up the rays of light from a heavenly body, bend them to a focus, form there an image and then present that image to the eye, for this is always explained in elementary books on physics, and hence it is unnecessary; but we do wish to make as clear as possible the meaning of the word *power* as it is used in defining the work of the telescope.

When we say the magnifying power of a telescope is 200,500 or any other number, we do not mean that the given numbers represent comparative areas, as the area of one circle with another, but we do mean the linear measure across the image as seen by the eye at the telescope compared to that of the visible object as seen by the unaided eye.

Hence astronomers have come to use the word "diameters" as a unit of measuring power instead of the use of the word "times." When they say a telescope magnifies 500 diameters, they mean that the diameter of the image is five hundred times greater than that of the object as seen by the naked eye. If we were to compare the area of the image with that of the object in this particular case, we readily see that the former would be 250,000 *times* as great as the latter. In other words the relation of linear diameters to times in area is always found by squaring the number representing the linear diameters of magnifying power. Thus, a power of one thousand in diameters would be equivalent to one million of times in area. To the inexperienced this relation and the very large number it suggests seem untrue and wholly impossible, but nothing in astronomy is better established than this fact.

The next inquiry naturally is concerning the methods of finding out the magnifying of any telescope. The methods in practical use are various and not at all difficult. They consist in comparing the focal lengths of the object glass and the various eye-pieces belonging to the telescope. For example the focal length of the object glass of Goodsell Observatory is 22 feet or 264 inches and that of one eyepiece is about 0.66 of an inch. The magnifying power of this particular eyepiece is therefore 400 diameters. The power of other eyepieces is determined in the same way, and the highest power which the largest telescope of the Goodsell Observatory carries is 1600 diameters. With this power, on a night of excellent "seeing" last year a very close double star was discovered and easily measured. The components of that new double star were so close together that they were nearly at the theoretical limit of the highest power of the telescope.

It is very rarely that we can use the high power of the telescope, because of the unsteadiness of the atmosphere. For it must be apparent to casual thought that when an observer is looking at a celestial body every tremor in the path of the light from that body through the atmosphere will be magnified in the same degree that the object itself is. So it is not an uncommon thing that the stars will dance in the telescope most tantalizingly while they look so beautiful, large and bright to the naked eye.

From what has been said some general idea may be gained how telescopes aid the eye in the study of distant objects.

Now a few words about the great Lick telescope at Mount Hamilton, Cal., may be of further use in the same way, because reading people often ask what the largest telescope can do in aiding the natural sight.

The highest power of the ordinary kind in regular use on that telescope is 2600 and the lowest 260. Higher powers of some special kinds have been employed in particular cases where such are suitable, but only under such circumstances.

The most useful powers for this instrument are 350, 520 and 1000. Of course much depends upon the object to be studied and the condition of the atmosphere in the use of all powers. The planets are best seen with 350 and 520 and the former is generally preferable. The nebulæ are ordinarily best seen with the lower power, unless a particular one is small and definite and then a power as high as 1000 is satisfactory. This power is by far the best in the study of the asteroids and ordinary double star work. When the atmosphere is clear and steady 1500 and 2600 are absolutely necessary and very satisfactory in measuring very

close double stars. But these powers can be used only for this kind of work under most favoring circumstances. They can not be used on the planets and strange as it may seem, Jupiter bears less magnifying than any other of the planets although the Jovian satellites stand very well under an eye-piece of 1000 diameters. These facts were given us recently by E. E. Barnard who has used the great telescope in all these lines of work. In the May number of *Knowledge*, 1894 (English) will be found a fuller statement of the most useful magnifying powers of this great telescope, made by both astronomers Barnard and Burnham.

GRATING SPECTROSCOPE FOR SMALL TELESCOPE.

DAVID E. HADDEN.

For Popular Astronomy.

In the June 1894 number of Popular Astronomy I gave a short sketch of a home-made spectroscope for use with a small telescope; since then I have received numerous letters from amateurs in various portions of this country and some foreign lands, asking for further information regarding its construction, price, etc.

I will endeavor to answer these inquiries now, by giving a description of my own instrument which has been changed somewhat from my original one referred to.

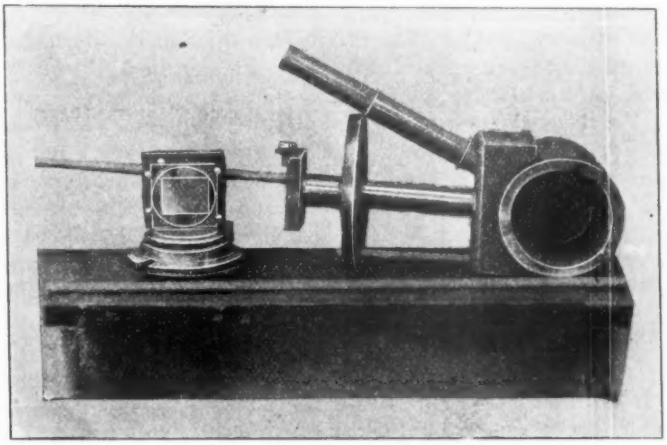
The tube of my 3-inch telescope was fitted by Mr. J. A. Brashear, Allegheny, Penn., with a rotating collar, containing apertures into which two round brass rods $\frac{5}{16}$ inches diameter are inserted. The rods were fastened to the ends of the grating box by means of screws.

Having a 2-inch Rowland grating I had the box made to fit it of the following dimensions: Outside diameter 3¾-inches, inside diameter 3¼-inches, length 4¼-inches (this size was necessary because the distance between the centers of the brass rods is 4 inches) the box was turned from a piece of very hard wood, and the two closely fitting end pieces fastened on with screws; a block of hard wood was fitted to the cylindrical front of the box, through which two holes for the collimator and observing telescope, were bored, so that they make an angle of about 27½ degrees at the center of the surface of the grating.

The object-glasses of both collimator and observing telescope are ¾-inch in diameter, focal length 6½-inches. An adjustable

slit is fitted to the collimator and a negative eye-piece magnifying about six or eight diameters used on the observing telescope.

A five inch circle of hard wood one-half inch in thickness is fitted near the slit end of the collimator, through the center of which the tube passes; holes are also bored for the brass rods, which are fastened to it with screws the observing telescope is also attached to the circle so that the entire instrument is light, strong and steady and easily adjusted to the large telescope.



The cut shows the spectroscope with one end of the grating box removed, to this is attached the T piece holding the grating which is rotated by means of a couple of geared wheels.

To attach the spectroscope to the telescope is but the work of a minute or so, simply inserting the rods into the collar the proper distance to secure a sharp image of the Sun or other object, on the slit plate, and clamping. Of course some adjustments are necessary with both collimator and observing telescope, for different orders of spectra, varying conditions of the atmosphere, etc.

As to the cost, the material for box, circle and rods need not exceed a dollar or so. Good achromatic lenses with tubes will cost about 3 or 4 dollars each. The slit is an important piece of mechanism and may be purchased or made. The grating, of course, will be the main item of expense, but a good one of about 1¼-inches diameter can be had from Mr. Brashear for about 15 to 20 dollars, which is not expensive, when it is considered that

in resolving power it equals many prisms and will afford the student an interesting and fascinating field of study in the new astronomy.

ALTA Iowa, Sept. 7th 1895.

THE SOLAR EPHEMERIS.*

J. MORRISON, M. A., M. B., PH. D.

FOR POPULAR ASTRONOMY.

For the computation of approximate values of the solar coördinates, etc., for places other than those on the meridian of Greenwich and Washington a column of "hourly variations" is added. The hourly variation of any quantity *at any time*, is the variation or change which would take place in an hour, if the rate of change *at that time*, were to continue uniform throughout the hour. This must not be confounded with the *average variation* which is defined as that hourly variation which if continued during an hour, would produce the change in the value of the quantity that actually does take place during this interval; thus if the difference between the values if a quantity at the times T and $T + t$ be divided by the interval t, the quotient is the average variation, but the hourly variation given in the ephemeris if continued uniform during the hour would *not* necessarily produce the change which the quantity actually undergoes in the same interval.

Let a_{-2}, a_{-1}, etc., be the values of any quantity such as the R A. or Decl. of the Sun or a planet for the dates T_{-2}, T_{-1}, etc., which are consecutive mean noons and let the 1st, 2d, etc., differences be formed as indicated in the following table:

Date.	Function.	1st Diff.	2d Diff.	3rd Diff	4th Diff.	5th iff.
$T-2$	a_{-2}					
		b_{-2}				
$T-1$	a_{-1}		c_{-2}			
		b_{-1}		d_{-2}		
T	a		c_{-1}		e_{-2}	
		b		d_{-1}		f_{-2}
T_1	a'		c		e_{-1}	
		b'		d		f_{-1}
T_2	a''		c'		e	
		b''		d'		
T_3	a'''		c''			
		b'''				
T_4	a''''					

* Continued from page 32.

Put $b + b' = 2b_0$, $c' = c_0$, $d' + d = 2d_0$, $e' = e_0$, etc., then we shall readily find

$$b = b_0 + \frac{1}{2} c_0,\ d' = d_0 + \frac{1}{2} e_0,\ d = d' + e' = d_0 + \frac{3}{2} e_0$$

and $\quad c = c' + d' = c_0 + d_0 + \frac{1}{2} e_0$;

the fourth differences may be assumed to be equal.

Now if $a^{(t)}$ denote the value of the function at any other date we have by the well known formulæ:

$$a^{(t)} = a + tb + \frac{t(t-1)}{1 \cdot 2} c + \frac{t(t-1)\ (t-2)}{1 \cdot 2 \cdot 3} d + \text{etc.},$$

and substituting the values of b, c, etc. as above. We easily find after reduction

$$a^{(t)} = a + t(b_0 - \frac{1}{6} d_0) + \frac{t^2}{2} (c_0 - \frac{1}{12} e_0) + \frac{t^3}{6} d_0 + \frac{t^4}{24} e_0 + \text{etc.},$$

and differentiating we have

$$\frac{d a^{(t)}}{dt} = b_0 - \frac{1}{6} d_0 + t(c_0 - \frac{1}{12} e_0) + \frac{t^2}{2} d_0 + \frac{t^3}{6} e_0 + \text{etc.}, \quad (14)$$

making $t = 0, \pm 1, \pm 2$ etc., we have the variations at the dates $T\ T_{-1}\ T_1$ as follows:

At T_{-2}	$b_0 - 2c_0 + \frac{11}{6} d_0 - \frac{7}{6} e_0$
T_{-1}	$b_0 - c_0 + \frac{1}{3} d_0 - \frac{1}{12} e_0$
T	$b_0 - \frac{1}{6} d_0$
T_1	$b_0 + c_0 + \frac{1}{3} d_0 + \frac{1}{12} e_0$
T_2	$b_0 + 2c + \frac{11}{6} d_0 + \frac{7}{6} e_0$

(15)

Of course each of these must be divided by the number of hours between the dates T, T_1 etc., as in the following example:

Date.	☿'s Decl.	1st Diff.	2d Diff.	3rd Diff.	4thDiff
	° ′ ″	′ ″	″	″	″
1895, May 1	+ 13 6 45.0				
		+ 50 37.5			
2	13 57 22.5		− 29.6		
		+ 50 7.9		− 11.0	
3	14 47 30 4		− 40.6		− 1.0
		+ 49 27.3		− 12.0	
4	15 36 57.7		− 52.6		
		+ 48 34.7			
5	+ 16 25 32.4				

Suppose we require the *hourly* variation in May $3^d\ 0^h$, we shall then have

$$b_0 = \frac{1}{2}(50'\ 7''.9 + 49'\ 27''.3)$$
$$= 49'\ 47''.6,\ c_0 = -40''.6,\ d_0 = -11''.5,\ e_0 = -1''.0$$

and hourly variation

$$= \frac{1}{24}\left(b_0 - \frac{1}{6}d_0\right) = +124''.56$$

which is recorded in its appropriate column opposite May 3. For May 3, 1^h we find the hourly variation to be

$$\frac{1}{24}(+49'\ 47''.6 - 40''.6 - 3''.83 - 0''.08) = +122''.63,$$

and so on.

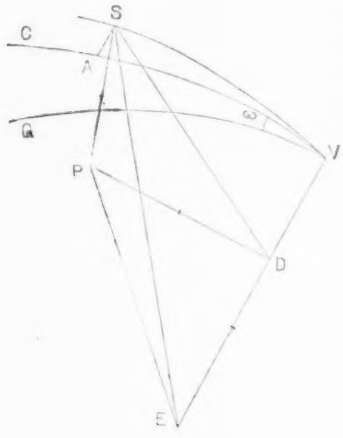
THE WASHINGTON EPHEMERIS.

This is computed from the Greenwich ephemeris just described by simply interpolating the various quantities for $5^h\ 8^m\ 12^s.04$—the west longitude of Washington. The R. A. Decl. and equation of time for *apparent* noon, are derived from those for Washington mean noon in precisely the same manner as has already been described, and therefore no further explanation is necessary.

The sidereal time at mean noon is obtained from that of Greenwich mean noon by adding the increase in $5^h\ 8^m\ 12^s.04$ which is $+9^s.8565 \times 5.1367 = 50^s.62988$.

THE SUN'S EQUATORIAL RECTANGULAR CO-ORDINATES.

The formulæ are given in the appendix and we here give the demonstration.



Let VQ represent the equator, VC the ecliptic, S the Sun, SA the Sun's latitude $= \beta$, VA the Sun's longitude $= \lambda$, CVQ the obliquity $= \omega$

$ED = X$, $DP = Y$ and

$SP = Z$, $SE = R$.

From the right triangle AVS we have

$$\sin\lambda = \tan\beta \cot AVS$$

or $$\tan AVS = \frac{\tan\beta}{\sin\lambda}$$

or $$AVS = \frac{\beta}{\sin\lambda} = \gamma \text{ suppose.}$$

Also $\cos VS = \cos \beta \cos \lambda = \cos \lambda$, since β is always less than 1″ and $\cos \beta$ may be taken = 1 and therefore VES may be taken equal to λ.

$$X = R \cos \lambda \tag{16}$$

$$\begin{aligned} Y &= DP = DS \cos SDP \\ &= R \sin \lambda \cos (\omega + \gamma) \\ &= R \sin \lambda \cos \omega \cos \gamma - R \sin \lambda \sin \omega \sin \gamma \\ &= R \sin \lambda \cos \omega - R\beta \sin \omega \\ &= R \sin \lambda \cos \omega - R\beta'' \sin 1'' \sin \omega \\ &= R \sin \lambda \cos \omega - R\beta'' \times 19.3 \text{ (in units of the seventh} \end{aligned}$$

decimal place) (17)

$$\begin{aligned} Z &= R \sin \lambda \sin SDP \\ &= R \sin \lambda \sin (\omega + \gamma) \\ &= R \sin \lambda \sin \omega + R\beta \sin 1'' \cos \omega \\ &= R \sin \lambda \sin \omega + R\beta'' \times 44.5 \text{ (in units of the seventh} \end{aligned}$$

decimal place) (18)

Differentiating (16) we have

$dX = - R \sin \lambda d\lambda$, but $R \sin \lambda = Y \sec \omega$ from (17) neglecting the term 19.3 $R\beta''$, and $d\lambda$ is negative being the reduction of the true longitude for precession and nutation, therefore we get

$$dX = Y \sec \omega d\lambda$$

which must be made homogeneous, dx being expressed in linear measure and $d\lambda$ in angular measure, hence multiplying the latter by sin 1″ and writing $\Delta X'$ and $\Delta\lambda$ for dX and $d\lambda$ respectively since they are not now to be regarded as infinitesimals we have

$$\Delta X' = + Y \sec \omega \, \Delta\lambda \sin 1'' \tag{19}$$

Differentiating (17) we get by the aid of (16) and (18) after rendering both members of the equation homogeneous

$$\Delta Y' = - X \cos \omega \Delta\lambda \sin 1'' + Z\Delta\omega \sin 1'' \tag{20}$$

and in a similar manner from (18) we find

$$\Delta Z' = - X \sin \omega \Delta\lambda \sin 1'' - Y\Delta\omega \sin 1'' \tag{21}$$

In the application of these last three formulæ the signs of $\Delta\lambda$ and $\Delta\omega$ must be regarded as positive; they are, however, *both negative*, being the reduction of the *true* longitude and *true* or *apparent obliquity* of date to the *mean longitude* and *obliquity* respectively. Thus for April 10, 1895, $\Delta\lambda = - 15''.73$ and $\Delta\omega = - 6''.33$, (see page 278 *Am. Ephem.*) but the negative sign is already taken into account in the formulæ in order to conform to the ephemeris, but the ephemeris is in error in regard to $\Delta\omega$ which is not "the reduction of the mean to the apparent obliquity."

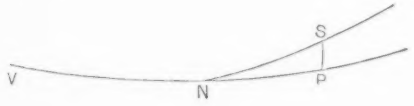
It now remains to explain the terms $-9.4\tau R\sin(\lambda+187^\circ)$ and $+21.7\tau R\sin(\lambda+187^\circ)$ which enter into the values of $\Delta Y'$ and $\Delta Z'$ respectively. They appeared for the first time in the *American Ephemeris* for 1869 and were evidently taken, without acknowledgement, from the Connaissance des Temps and up to the year 1886 the formulæ for $\Delta Y'$ and $\Delta Z'$ contained two symbols for the Sun's longitude. These terms take into account the motion of the ecliptic itself due to the attraction of the planets. The great circle with which the ecliptic coincided at the beginning of the year 1750 was taken by Laplace as the fundamental plane to which all subsequent and preceding positions of the ecliptic are to be referred. If Π denote the longitude of the ascending node of the actual ecliptic at any subsequent date t, upon the fixed ecliptic reckoned from the equinox of 1750.0 and π, the mean annual motion of the obliquity of the actual ecliptic to the fixed plane, we have according to the researches of physical astronomy

$$\Pi = 171^\circ\ 36'.2 - 5''.21t$$
and $$\pi = 0''.4889t - 0''.00000307t^2$$

and for 1850 we shall find

$$\Pi = 171^\circ\ 36'.2 + 50''.2\times 100 - 5''.21\times 100$$
$$= 172^\circ\ 51'\ 2 \text{ or } 173^\circ \text{ approximately}$$

and from the second of the above equations we see that the annual change in π is $0''.4889$—some authorities give $0''.48$ and others only $0''.46$.



Now referring the Sun's place to the ecliptic and equinox of the beginning of the year and denoting the changes in Y and Z by ΔY_2 and ΔZ_2 due to this cause and we shall evidently have

$$Y_2 = R\cos\omega \text{ and } Z_2 = R\sin\omega$$
and $$\begin{aligned}\Delta Y_2 &= -R\sin\omega\, d\omega\\ \Delta Z_2 &= +R\cos\omega\, d\omega\end{aligned} \qquad (22)$$

where $d\omega$ may be regarded as the Sun's latitude referred to ecliptic of beginning of the year.

Let NV be the ecliptic of any fixed epoch and SN the ecliptic of any subsequent epoch t: Now we know that NS has a uniform motion around the node N and that $VN = 173^\circ$.

Draw SP perpendicular to NP, then we have

$$SP = d\omega,\ NS = \lambda - 173^\circ,\ \text{and}\ PNS = 0''.4889t$$

t being expressed in years or fractions of a year; then

$$\sin PS = \sin PNS \sin NS$$

that is
$$d\omega = 0''.4889t \sin (\lambda - 173^\circ)$$
$$= 0''.4889t \sin (\lambda + 187^\circ)$$

substituting in (22) we find

$$\Delta Y_2 = - Rt \sin \omega \sin 1'' \sin (\lambda + 187^\circ) \times 0''.4889$$
$$\Delta Z_2 = + Rt \cos \omega \sin 1'' \sin (\lambda + 187^\circ) \times 0''.4889$$

Computing the numerical value of the coefficients

$$\sin \omega \sin 1'' \times 0''.4889 \text{ and } \cos \omega \sin 1'' \times 0''.4889$$

we have

$\sin \omega = 9.5998756$	$\cos \omega = 9.9625532$
$\sin 1'' = 4.6855749$	$\sin 1'' = 4.6855749$
$0''.4889 = 9.6892200$	9.6892200
$.0000009,43 = 3.9746705$	$.0000021,74 = 4.3373481$

Therefore we have for the corrections due to the motion of the ecliptic and referred to mean equinox of the beginning of the year,

$$\Delta Y_2 = - \ 9.4tR \sin (\lambda + 187^\circ)$$
$$\Delta Z_2 = + \ 21.7tR \sin (\lambda + 187^\circ)$$

$\Delta X'$ is evidently not affected by this motion.

We will close this paper with the following example:

Find the Sun's equatorial rectangular coördinates on 1895, Aug. 8.0 G. M. T., having given $\lambda = 135^\circ\ 39'\ 4''$; $\beta = + 0''.24$ $\Delta\lambda = 36''.11$ (see page 278); $\Delta\omega = 8''.57$, $\log R = 0.0058962$ and $\tau = .616$.

$\log R = 0\ 0058962$	0.0058962	$0\ 0058952$
$\cos \lambda = 9\ 8543647n$	$\sin \lambda = 9\ 8444932$	9.8444932
	$\cos \omega = 9.9625451$	$\sin \omega = 9.5999189$
$\log X = 9.8602609n$	$9\ 8129345$	9.4503083
$X = -.7248713$	$+ 0.6500316,3$	$+ 0\ 2820384,4$
	$\log 19.3 = 1\ 2855573$	$\log 44.5 = 1.6483600$
	$R = 0\ 0058962$	$0\ 0053962$
	$\beta = 9.3802112$	9.3802112
	0.6716647	1.0344674
	4.695	10.826
	$Y = + 0.6500312$	$Z = + \ .2820395$

$\log Y = 9\ 8129341$	$\log X = 9.8602609$	$\log -X = 9.8602609$
$\sec \omega = 0.0374549$	$\cos \omega = 9.9625451$	$\sin \omega = 9\ 5999189$
$\Delta\lambda \sin 1'' = 6.2432024$	$\Delta\lambda \sin 1'' = 6\ 2432024$	$\Delta\lambda \sin 1'' = 6\ 2432024$
$\log \Delta X' = 6.0935914$	6.0660084	5.7033822
$\Delta X' = + 0.0001240$	$+ 0.0001164,15$	$+ 0.00005051$

$$\begin{array}{rl|rl}
\log Z & = 9.4503099 & \log -Y & = 9.8129341n \\
\Delta\omega \sin 1'' & = 5.6185557 & \Delta\omega \sin 1'' & = 5.6185557 \\
\hline
 & 5.0688656 & & 5.4314898n \\
 & + 0.0000117{,}18 & & - 0.0000270 \\
\hline
\log -9.4 & = 0.97313n & \log 21.7 & = 1.33646 \\
rR & = 9.78602 & rR & = 9.78602 \\
\sin(\lambda+187^\circ) & = 9.78296n & \sin(\lambda+187^\circ) & = 9.78296n \\
\hline
 & 0.54211n & & 0.90544n \\
 & + 3.48 & & - 8.04 \\
\Delta Y' & = + 0.0001285 & \Delta Z' & = + 0.0000227
\end{array}$$

The use of the Sun's equatorial rectangular coördinates will be shown in a subsequent paper on the planetary ephemerides.

[TO BE CONTINUED].

PROBLEMS.

15. When the altitude of a star is equal to the latitude φ of the place of observation show that

$$\cos = P \tan \varphi \tan \left(45^\circ - \frac{\delta}{2}\right)$$

and $$\sin \frac{1}{2} A = \sec \varphi \sin \left(45^\circ - \frac{\delta}{2}\right)$$

where P is the hour angle, A the azimuth and δ the declination.

16. When does the altitude of a celestial body vary most rapidly?

17. In latitude $+ 38^\circ$ at the time of the equinox find the time occupied by the Sun in rising or setting, supposing his semi-diameter $16'$.

18. Given the latitude of the place and the Sun's semi-diameter, find the declination when the difference between the times of rising or setting of the upper and lower limbs is a minimum.

19. Is it strictly true that the azimuth of a celestial body is not affected by parallax? And if not, why not?

20. At a given place, show that the velocity in azimuth at rising and setting is constant for all stars.

21. If E denote the *maximum* value of the equation of time due to the *obliquity* alone, prove the following relations

$\cot \lambda = \cos \delta$, $\cot^2 \lambda = \cos \omega$, and

$\sin E = - \cos 2\lambda$, λ being the Sun's long. and δ the Decl.

(This problem proposed by Mr. O. E. Harmon, Chehalis, Wash).

ERRATA.

In Prob. 1, for $\cot \frac{\omega}{2}$ write $\cot^2 \frac{\omega}{2}$.

In Prob. 13, for $\Delta\alpha = - \tan \delta \Delta\omega$ write $\Delta\alpha = - \tan \delta \cos \alpha \Delta\omega$.

M.

THE CONSTELLATIONS FOR OCTOBER.

Directly overhead, at 8 o'clock, the long constellation, shaped like a cross, lying in the Milky Way with the head toward the north, is Cygnus, The Swan. Toward the west from this one will see the first magnitude star Vega, in Lyra, the brightest star now visible. Two fainter stars form an equilateral triangle with Vega. Farther to the west six stars of medium brightness form the large K of Hercules. Lower down is the curved group of the Northern Crown and very near the horizon the ruddy Arcturus in Bootes is just about to set.

Turning toward the south the most conspicuous star is Altair in Aquila, a first magnitude, with fainter ones on either side forming a straight line in the east edge of the Milky Way about half way to the zenith. Just north of this is Sagitta, an arrow shaped group of four faint stars. On the west side of the Milky Way is Ophiuchus, the Serpent-bearer, a large rambling constellation with no very conspicuous stars, but in which one can easily trace the convolutions of the Serpent. A little east and north of Altair is a small diamond shaped group of five stars, The Dolphin, sometimes known as Job's Coffin. Lower down in the south Capricorn and Aquarius have no conspicuous stars, but the Y of Aquarius will be easily recognized. Toward the southeast the great square of Pegasus cannot escape notice. The star in the N. E. corner of the square is also at the head of Andromeda, whose body extends toward the northeast, marked by two cross-rows of three unequal stars each. Below Andromeda, Pisces, Aries and Cetus are rather difficult to trace. Toward the east the Pleiades have risen and above them Perseus shows a number of bright stars in the Milky Way. Among them is Algol the variable. Low in the northeast is Auriga with the first magnitude star Capella.

Looking toward the north one sees near the horizon Ursa Major, The Great Bear; above that Draco, half encircling Polaris and Ursa Minor; and finally overhead the K of Cepheus and the W of Cassiopeia.

No planets are visible at this early hour of the night. Mercury has set; Neptune has barely risen and the others are all too near the Sun, except Jupiter which may be observed only after midnight.

Minima of the Variable Stars of the Algol Type.

[Given to the nearest hour in Central Standard Time.]

U CEPHEI.

	d	h
Nov.	3	12
	8	12
	13	12
	18	11
	23	11
	28	11

ALGOL.

	d	h
Nov.	3	13
	6	10
	9	7
	20	18
	23	15
	26	11
	29	8

λ TAURI.

	d	h
Nov.	11	18
	15	17
	19	15
	23	14
	27	13

R CANIS MAJ.

	d	h
Nov.	1	10
	2	13
	3	17
	9	9
	10	12
	11	16
	18	11
	19	14
	20	17
	26	10
	27	13
	28	16

S CANCRI.

	d	h
Nov.	12	13

U CORONÆ.

	d	h
Nov.	18	9
	25	7

U OPHIUCHI.

	d	h
Nov.	1	7
	6	8
	12	5
	17	6
	21	6

Y CYGNI.

Even Epochs.

	d	h
Nov.	3	9
	6	9
	9	9
	12	9
	15	9
	18	9
	21	9
	24	9
	27	9
	30	9

Odd Epochs.

	d	h
Nov.	1	13
	4	13
	7	13
	10	12
	13	12
	16	12
	19	12
	22	12
	25	12
	28	12

Z HERCULIS.

	d	h
Oct.	2	8
	4	7
	6	8
	8	7
	10	8
	12	7
	14	8
	16	7
	18	8
	20	6
	22	7
	24	6
	26	7
	28	6
	30	7
Nov.	3	7
	7	7
	11	7
	15	6
	19	6

NOTE.—I am indebted to P. S. Yendell for the above ephemeris of Z Herculis, which is based on a period 7 — 10 sec. longer than that used by Hartwig.

Maxima and Minima of Long Period Variables.

1. Three observed maxima of 1113 U Arietis are available for the purpose of prediction. Taking the mean of four observers the interval between the first and second maxima is 380 days, between the second and third, 354 days. Adding the mean of these two periods, 367 days, to the time of the last observed maximum, 1894, Nov. 2, gives 1895. Nov. 4 as the prediction for the next maximum. On the supposition that the period is alternately longer and shorter, and applying the first interval, 380 days, brings the maximum Nov. 17. Chandler's ephemeris was published before the maximum of 1894 occurred.

2. The period used by Chandler for 7085 RT Cygni seems too short. For the last four observed maxima the correction to the ephemeris has increased from -8 days to $+25$ days, (mean of six observers). It therefore seems probable that the next maxima will occur about 1896, Jan. 14.

MAXIMA.

1895 November.

Date.	No.	Star.
2:	1981	S Camelopar.
2	2735	U Canis min.
3	7234	R Capricorni.
3	7252	W "
5	2857	U Puppis.
5:	5928	T Ophiuchi.
8	5617	U Libræ
13	3890	W Leonis.
14	2266	V Monocero.
17	5194	V Bootis.
17	5795	W Scorpii.
24	7192	Z Cygni.
25	5931	S Ophiuchi.
26	5157	S Bootis.
26	7909	S Piscis aus.
27	2946	R Caneri.
30	5776	X Scorpii.

1895 December.

3	893	U Ceti.
3	5430	T Libræ.
7	5887	V Ophiuchi.
8	6062	RR Scorpii.
9	806	*o* Ceti (Mira)

MAXIMA CONT.

1895 December.

Date.	No.	Star.
11	2684	S Canis min.
12	1717	V Tauri.
13	2976	V Caneri.
13	7779	S Cephei
13	8230	S Aquarii.
14	4596	U Virginis.
15	5831	S Scorpii.
18	3637	S Carinæ.
18	7455	U Capricorni.
21	434	S Piscium.
21	845	R Ceti.
21	1113	U Arietis.[1]
24	7085	RT Cygni.[2]
27	7242	S Aquilæ.
30	6905	R Sagittarii.
30:	6923	Z "
31	5037	RR Virginis.

MINIMA.

1895 November.

1	1771	R Leporis.
3:	5095	R Centauri.
8	5190	R Camelopar.

MINIMA CONT.

1895 November.

Date.	No.	Star.
14	466	U Piscium.
17:	494	R Sculptoris.
22	3418	R Carinæ.
26:	6682	X Ophiuchi.
27	5675	V Coronæ.
29	5338	U Bootis.
30:	1582	S Tauri.

1895 December.

6:	112	R Andromed.
9	7560	R Vulpeculæ.
10:	6943	T Sagittæ.
12	1292	R Persei.
20:	7456	RR Cygni.
20	7577	X Capricorni.
21:	7659	T "
22:	3994	S Leonis.
22	6512	T Herculis.
23	3825	R Ursæ Maj.
24	4847	S Virginis.
24	7139	RR Sagittarii.
28	5950	W Herculis.
29	2583	L_2 Puppis.

A colon after the date indicates doubt.

The authorities for the above are Hartwig's ephemeris in the Vierteljahrschrift for the Algol stars, and Chandler's ephemeris in the Astronomical Journal for the long period variables.

J. A. PARKHURST.

Marengo, Ill., 1895, Sept. 7.

Ephemeris of Short-Period Variables for October.

The following ephemeris of variable stars of short period is given in the hope of stimulating some effort toward their observation.

The times of maximum and minimum are computed from the elements given in Chandler's Second Catalogue, with the exception of the cases of β Lyræ, which is taken from the Companion to the "Observatory."

It is intended to continue this ephemeris from month to month.

OCTOBER.

[Greenwich Mean Time].

2279 T MONOCEROTIS.

Max.	Min.
1.34	20.41
28.34	

2509 ζ GEMINORUM.

Max.	Min.
6.51	1.49
16.66	11 65
26.82	21 80
	31.96

6368 X SAGITTARII.

Max.	Min.
3 29	
10.30	7.43
17.31	14.44
24.33	21.45
31.34	28 46

6404 Y OPHIUCHI.

Max.	Min.
4.48	
21 61	15.36

6472 W SAGITTARII.

Max.	Min.
7 30	4.30
14.89	11 89
22.48	19 48
30.08	27.08

6573 Y SAGITTARII

Max.	Min.
4.52	2 72
10.29	8.49
16.06	14.26
21.83	20 04
27.61	25.81
	31.58

6636 U SAGITTARII.

Max.	Min.
4.61	1.64
11.36	8.38
18.10	15.13
24.85	51.88
31.59	28.62

6758 β LYRÆ.

Min.
11.43
24.50

6984 U AQUILÆ.

Max.	Min.
5 58	3.33
12 60	10.35
19.63	17.38
26.66	24 41
	31.43

7124 η AQUILÆ.

Max.	Min.
4.02	1.64
11.20	16.00
18.37	23 17
25.55	30.35

7149 S SAGITTÆ

Max.	Min.
1.45	6 43
9.83	14.82
18.22	23.20
26.60	31.58

7437 X CYGNI.

Max.	Min.
1.35	
17.74	10 94
	27.33

7483 T VULPECULÆ.

Max.	Min.
1.89	
6.33	5.03
10.76	9 46
15 20	13.90
19 63	18.33
24 07	22.77
28 51	27.21
	31.64

8073 δ CEPHEI.

Max	Min.
5 49	3.89
10.86	9 25
16 13	14 61
21 49	19 98
26 86	25.35
	30.72

Dorchester, Mass., 1895, Sept. 13.

PAUL S. YENDELL.

COMET NOTES.

Discovery of a New Comet, *a* 1895.—On the morning of August 21, Dr. Lewis Swift discovered a new comet in the constellation Pisces. Its position was then: Right ascension $0^h\ 27^m\ 40^s$; Declination north 5° 30′. The comet was observed and its position accurately determined on the next morning by Barnard at Lick Observatory, and others secured observations later. At Goodsell Observatory the comet was first seen on the morning of the 24th. We found it easily by sweeping with the 5-inch finder attached to the 16-inch telescope. It was faint, round, and diffuse; about 5′ in diameter, with a very slight central condensation. In the 16-inch telescope only the central part, perhaps 1′ in diameter, could be seen. No nucleus was noticed at this time. On subsequent nights a very faint nucleus was discerned. Our impression was that the comet was growing brighter up to Aug. 31. Since the Moon has passed out of the way again, however, we have seen the comet only on one occasion and then clouds coming up unexpectedly prevented our determining its position. It was exceedingly faint and on subsequent nights we failed to see it.

The best elements of the comet which are yet at hand are those of Dr. A. Berberich, which indicate that it is one of short period. These elements are quite uncertain and the period is likely to be somewhat greater, probably about 5 or 6 years.

ELLIPTIC ELEMENTS OF SWIFT'S COMET.

$T = 1895$, Aug. 25.49946 Berlin M. T.
$\omega = 171° 45' 1''$
$\upsilon = 168\ 31\ 32$ } 1895.0
$i = 2\ 27\ 27$
$\varphi = 25\ 50\ 9$
$\mu = 1100''.81$
$\log a = 0.338863$
Period = 3.223 years.

How I Found the Comet.—The finding of Comet (*a*) 1895 was accomplished in the following singular and fortuitous manner: the last nebula discovered at the Warner Observatory, Rochester, N. Y., just prior to the dismantling of that institution, had never been catalogued or published, so, on the morning of August 21st, the nebula being near the meridian, it occurred to me to look it up and secure, perhaps, a more accurate position, and test its brightness, if there were a difference, as seen there and here. Setting the 16-inch telescope to the place of the object I saw to my astonishment a beautiful comet instead of the expected nebula. A single glance assured me of its cometary character which its motion after a time confirmed. From its situation I inferred it to be a periodic, probably another of the Jupiter family of comets. A bright elliptical condensation was visible at the centre of the coma, and, at occasional intervals of good seeing, a minute starlike nucleus was seen which would appear and disappear like the star in the center of the planetary nebula. (General Catalogue, 4514). Its orbital elements have been computed by Professors Hussey and Boss, but its periodic time has not been ascertained, both because of its unfavorable position and its slowness of motion.

Its announcement was delayed for several hours because of the absence of my son, Edward D., the assistant astronomer, and the only telegrapher on the mountain, who had gone on his annual vacation. No telegram was possible until the electric car could convey me to Altadena, the nearest telegraph office, at 8 A. M. LEWIS SWIFT.

Lowe Observatory, Echo Mountain, Cal.,
September 9, 1895.

PRACTICAL SUGGESTIONS

121. What effect, if any, does a change of temperature have upon the figures or relative form of the two lenses that make up a telescope objective? Does the effect of cold cause the crown lens being less dense than the flint to contract more than the flint lens does under same temperature? If so does it destroy the achromatism of the combination? That it does is the assumption on which Mr. Gathmann bases his so-called invention of sectional lens objective. W. E. S.

Answer:—No appreciable effect can be seen in the achromatic objective from variations of temperature, where the changes are *very slow*, but if the changes are rapid, the "figure" of the objective alters so much as to make it useless for

critical observations until the whole glass assimilates to the temperature, when it will perform as well as in other temperatures.

Let us suppose that the temperature of our Observatory is 50°; we open the slit, and expose the objective to an outside temperature of 40°. The outside surface will suffer contraction, and the objective will become under corrected for spherical aberration.

In the case of a small objective the entire glass will soon take up the outside temperature, and become normal in shape, but in the case of very large objectives the change is slower, according to the mass of material in the lenses. We find in testing large lenses, that the time it takes a glass to come to normal shape is directly proportional to the mass.

It is well for astronomers to know this fact, for while it does not affect the chromatic aberration to a degree that is at all hurtful it does affect the spherical aberration, and a glass, although otherwise perfect for figure, when the temperature conditions are changing rapidly, will not do good work.

Mr. Gathmann's glass will be no exception to this rule.

It is important in the final testing of an objective to have the conditions as nearly perfect as possible, and this is why the optician does his fine testing in an underground apartment, where he can make the conditions of temperature as he wants them, even then he has to contend with the disturbing effects of his polishing. After a surface has been polished, say of 20-inch lens, the optician must wait several hours before he is certain that the molecular disturbance caused by the polishing of the surface has ceased to have any effect.

Were it possible to get rid of disturbances caused by differences of temperature, the optician's task would be many times easier, and the observer would not blame the object-glass maker for bad images and wonder how, at times, the object-glass would give splendid images, at other times miserable ones. J. A. B.

122. How is light dispersed by a grating? If done by reflecting why should a reflecting telescope be perfectly achromatic? C. D. H.

Answer:—There is a great difference between a reflecting telescope mirror and a reflecting grating.

The mirror of a reflecting telescope is polished to a true parabolic curve, so that it will reflect parallel rays to an accurate focal point or plane, and as all the waves of light are reflected equally—*i. e.* at the same angle, and there is no separation of the long or short waves, it is evident that the image formed by such a mirror must be truly achromatic.

But a reflecting grating is a totally different affair. The mirror for a reflecting grating is made either plane or concave and as a mirror, we get no more color effects from it than we do from the mirror of the reflecting telescope.

It is not until its surface is grooved with from say 500 to 20,000 lines to the inch with a diamond point by the aid of marvelously accurate mechanism that white light is broken up into its component colors by the interference of its different waves, so that the chromatic effects of the reflecting grating are due primarily to the grooving of the polished surface, and not so polish alone. J. A. B.

123. How to clean the diffraction grating.

In the December, '94, No. of POPULAR ASTRONOMY I gave an item in answer to an inquiry regarding the cleaning of diffraction gratings.

As it had been suggested to Professor Hale by a German physicist, I tried it several times with most perfect success. Since that time I have had several failures—indeed upon one occasion a large grating was almost ruined by a brown-

ish patina forming upon the surface that could not all be removed by any subsequent treatment.

Professor Hale had the same misfortune with a 5-inch grating belonging to the Kenwood Observatory. I have made several trials upon plates, spoiled in the ruling, and find there is no certainty about the method. It may be in the ammonia, or it may be in slight differences in the metal, at any rate I send this note asking those who have gratings, not to use the method until further experiments are made to find out if possible the reason why some gratings will clean beautifully and others are made worse by the method.

Professor Adeney, of the University of Dublin, writes me he has good success using a method suggested by Professor Hartley, of the College of Science. A mixture of ether and absolute alchohol is applied to a soft clean chamois and the grating carefully wiped in the direction of the lines.

I am inclined to agree with Professor Lieving in letting the surfaces severely alone, save to brush off accumulated dust with a tuft of cotton or camel's hair brush.

Professor Lieving does not believe the inevitable bloom which forms on a plate, after years of use, practically affects the grating. J. A. BRASHHEAR.

124. I have seen the statement in a treatise on astronomy that the motions of the satellites of Jupiter, numbered one and two, when in position of new Moon are retrograde. I can not understand what force will stop the direct motion of the moons and produce the opposite. J. D. D.

The direct motion is not stopped. These satellites always go around their orbits in a direction opposite to that of the hands of a watch, but to an observer on the Sun or Earth this motion carries them from left to right when they are in the position corresponding to new moon and from right to left when they are in the opposite part of their orbits. Aside from this motion about Jupiter the satellites are carried along with the planet in his motion about the Sun and their actual motion is found by taking into account both of these motions, their sum in the latter case, since both motions are then in the same direction, their difference in the former (New Moon) case.

If there were a satellite at a distance of 461,000 miles from Jupiter its velocity of revolution about the planet would just equal the velocity of revolution of Jupiter about the Sun and when it was between Jupiter and the Sun the two components of its motion would balance each other so that like the bottom point of a wagon wheel it would go neither forward nor back, so long as it remained the bottom point. The first and second satellites of Jupiter are less than 461,000 miles from the planet and their motions of revolution about the planet are therefore greater than that of the fictitious satellite we have above supposed, while the motions of revolution of the third and fourth satellites are less since they are more than 461,000 miles distant from their primary. In the case of the two inner satellites the motion of revolution is more than sufficient to balance the forward movement of the satellites with Jupiter in his orbit and a retrograde movement is the result. In the case of the outer satellites, and also in the case of our own Moon, the motion along the orbit of the planet more than balances the motion of the satellite about the planet and the resulting movement of the satellite is never retrograde.

The limit at which the two motions of the satellite just balance each other is found by multiplying the mass of the planet by its mean distance from the Sun.

G. C. C.

125. Can some one suggest some cheap form of driving clock for a 3-inch

equatorial, which has slow and quick motion in R. A. and 4½-inch hour circle? Some method other than the sand clock preferred. H.

126. When, before this year, were there two total eclipses of the Moon visible in this country during the same year? D. S.

Answer: By this country, we suppose the querist means the United States. A pair of total eclipses similar to those of this year occurred in 1855 on May 1 and October 24 and also in 1862, June 11 and December 5.

GENERAL NOTES.

This number of our publication is sent only to those subscribers who have renewed or ordered a continuance of Volume III. Our friends will please understand that it is not our wish to cut off subscribers because they are not very prompt in renewals, but rather it is our desire not to send a single copy to any one who does not want it. For this reason we have taken the time and incurred the expense to write to every subscriber promptly after expiration of subscription that we might obtain this information. The response has been very general, very prompt and very encouraging.

We have also written very many letters asking subscribers, if, in their opinion, we were meeting the real wants of those for whom this publication is intended, viz:—amateurs, students of astronomy, teachers and popular readers. Replies to this query have been quite different, although uniformly kind and full of interesting suggestion. The amateurs and students of astronomy, more or less advanced, have commended our past plans of study and work, but the teachers and the popular readers have often suggested that our matter in the last volume was much too technical to be of much service to them.

We believe that this criticism is just, and we have tried in this number to modify our plan somewhat so as to offer a relief in this direction. It is not generally because the themes treated are in their nature beyond common comprehension, but rather because of the manner of their treatment. Any astronomer who *understands* any theme in the whole range of the science can make that theme in its essentials perfectly plain if he will take the time and trouble to do so.

We have left out most of our tables, to give place to more popular matter, and matter of a more general nature. Our readers will remember that our last issue contained planet notes and tables for October, and that this matter will be continued in another form for November in the next number. We think our new plan of illustration in connection with this matter will be pleasing and more serviceable generally. We hope to receive suggestions from any one in regard to changes.

From what has been said, we hope it will not be inferred that the matter to be presented in this publication, in the future, will be less important or useful in character than it has been in the past. Such a view is the farthest from that entertained by those in charge of its management. On the contrary it is their desire to enhance its real and general value in all possible ways within their reach, and to this end the aid of all interested is most earnestly and cordially solicited. In this number we have added eight pages to help amateurs in the harder study of the Solar Ephemeris.

We publish in this number an interesting account of the great services of Benjamin Peirce to American Science No one of our astronomers or mathematicians has done more for his country's development and reputation than Peirce, nor is any more worthy to be held in everlasting remembrance by a grateful people. It is almost impossible for an American to read Dr. See's eloquent tribute to this great and good man, without feeling that while Peirce's labors have always been known and appreciated by scholars, his name is not so well known to the public as it ought to be. The name of Peirce ought to be a familiar word in every school of the country. The influence of such an ideal is all the more elevating because in Peirce nature combined the most exalted personal character with the highest scientific genius and thus produced one of her noblest developments. The widespread danger of retrogradation in scientific ideals incident to an age of degeneracy renders it all the more necessary for those who are devoted to the sacred cause of science to hold aloft the achievements of illustrious men in order that their merits and virtues may be adequately commemorated.

What Prominent Astronomers are Doing.—Dr. T. J. J. See, of the University of Chicago, has been occupied for some time with a revision of all the double-star orbits which are capable of satisfactory determination at this time. He hopes to find forty fairly good orbits, which will serve as a foundation for his researches on the formation of stellar systems. These researches in Cosmogony are of vast importance, and the results will be anxiously awaited by astronomers. In the meantime Dr. See is going over the orbits in detail so as to ensure satisfactory elements, and in order that every orbit may be represented in exact accordance with the facts as known at this epoch. During the latter part of September, Dr. See spent several days at Washburn Observatory at Madison, Wisconsin, in the use of the large telescope of that Observatory for the purpose of measuring some double-stars and for other work pertaining to other studies now under prosecution.

Professor Simon Newcomb, Superintendent of American Ephemeris and Nautical Almanac, Washington, D. C., is now engaged in completing and passing through the press the new tables of the four inner planets, on which he has been at work for many years.

Prof. E. E. Barnard of Lick Observatory has recently been measuring the diameters of the planets, at work on double stars, and photographing the Milky Way. He has measured the diameters of Mercury, Venus, Mars, Saturn, Jupiter, Uranus, Neptune, Ceres, Pallas, Juno, Vesta and the four bright satellites of Jupiter. He has also done considerable miscellaneous work such as measuring the positions of comets, nebulæ and the like, which need not here be named.

Professor George E. Hale, director of the Yerkes Observatory, Lake Geneva, Wis., is at work in a temporary Observatory at Lake Geneva endeavoring to map the corona without an eclipse. The method employed is that described in his paper in a recent number of the *Astrophysical Journal.* Briefly, a pair of bolometers is used in an attempt to measure the heat radiation from the different parts of the corona. He has been much delayed in various ways so that this interesting method has not yet been really tested. Professor Hale entertains strong hope of ultimate success.

Professor Ormond Stone, director of the Leander McCormick Observatory, University of Virginia, has been of late more especially interested in the satellites of Saturn of which Mr. Lovett and himself have made a large number of measures during the last two years. These measures are published in installments in the *Astronomical Journal* of Cambridge, Mass., two of which have already appeared and others will follow at brief intervals. These observations will be discussed during the year. Just now Professor Stone is printing a monograph on the nebula of Orion. Gordon E. Buck, a graduate of the University of Virginia, and S. J. Barnett, a graduate of the University of Denver, are with him this year. Mr. E. O. Lovett took the degree of Doctor of Philosophy from the University last June. His dissertation was on the Great Inequality of Jupiter and Saturn and was published in the *Astronomical Journal.* He is now studying in Leipzig.

Professor C. A Young, of Princeton, N. J., has recently revised his "Lessons in Astronomy" and the copy was in the hands of the printer about the first of September. He is now engaged in revising his other text-books, known as "Elements of Astronomy" and "General Astronomy." He also expects to complete the revision of his earlier work entitled "The Sun" as soon thereafter as possible.

Professor H. A. Howe of Chamberlin Observatory, University Park, Colorado, besides heavy University work has recently had opportunity only to do some observing work upon comets in view. During vacation months Professor Howe has conducted a summer school. We are happy to announce that Professor Howe is to prepare for this publication a series of papers on the adjustments of small telescopes. The first article will appear in our next issue.

Professor D. P. Todd of Amherst College Observatory, besides regular college duties, is engaged at present in editing his *Columbian Knowledge Series*, published by Roberts Brothers of Boston, several numbers of which will relate to astronomical subjects. The volume next issued and now in press is entitled *Stars and Telescopes*, a *hand book of Astronomy* based upon the last edition of Lynn's excellent *Celestial Motions*, to which he has made copious additions. Professor Todd has also well in hand the necessary arrangements for an expedition to observe the total eclipse August 29, 1896. The instruments are already partly designed and it is hoped to begin work on their construction within a few days.

The funds for the new Observatory at Amherst have been promised and preliminary plans are drawn, but the beginning of construction will probably be deferred until next year.

Professor Asaph Hall, Jr., Director of the Detroit Observatory, University of Michigan, Ann Arbor, is now at work on lists of latitude stars with the Meridian Circle. These stars are to be used at Georgetown College and Sault Ste. Marie. With the same instrument he is also observing Polaris for latitude above and below the pole, direct and reflected.

The Total Eclipse of the Moon, Sept. 3, 1895.—At Northfield the sky though cloudless was quite thick with haze at the beginning of the eclipse, but the haze cleared away toward the middle and at the end of totality the sky seemed perfectly clear. The eclipse was observed by Professors Payne and Wilson

with the 4-inch and 16-inch telescopes. The penumbral shading was noticeable to the naked eye at 9:45 Central time and grew gradually darker until the dark shadow appeared at just about the predicted time. The time recorded was 10^h $0.^m5$, which was certainly a little late. The shadow was at first very dark; to the naked eye it was almost black; in the 16-inch telescope it appeared of a dark grey color, turning to a lighter grey as it progressed across the disc of the Moon. None of the features of the Moon's surface were visible in the shadow until 10^h 10^m, when the crater Aristarchus was dimly seen. Soon after this many of the brighter surface markings became visible in the shadow with the 16-inch, while wholly invisible with the 5-inch finder.

The first copper tinge to the shadow was noticed at 10^h 7^m, and as the Moon penetrated farther into the shadow, the portion most deeply immersed grew gradually brighter until after the beginning of totality which was noted at 11^h $6^m.5$. Later it appeared to enter a darker part in the center of the shadow. At the middle of totality the east and west limbs of the Moon were both decidedly brighter than the central portion which was of a dusky copper hue. At 11^h 50^m the east and west limbs were equally bright, but at 12^h 0^m the eastern limb was the brighter. At 12^h $46^m.5$ the eastern limb was so bright that it seemed almost fully illuminated and at 12^h 47^m the end of totality was noted. The edge of the shadow was then quite a light grey and almost all the features of the Moon's surface could be seen through it.

As the shadow passed off the phenomena were the same, in the reverse order, as those noted on its approach, except that the shadow was by no means so dark. In the 16-inch telescope the main features of the surface covered by the shadow were not lost at any time. The ruddy color extended to within 2′ or 3′ of the edge of the shadow. It was lost to sight at 1^h 50^m A. M., four minutes before the shadow passed off. The penumbral shading was quite noticeable, covering the whole bright part of the Moon at 1^h 28^m and extending to the center o the disc at 1^h 54^m, the end of the eclipse. H. C. W.

The Total Lunar Eclipse of 1895, Sept. 3.—The night proved very satisfactory for observing and photographing the total eclipse of the Moon Sept. 3. My observations were confined to the naked eye, and the 2½-inch guiding telescope of the Willard lens.

The contacts were observed with the usual uncertainty. Possibly, however, this uncertainty was somewhat diminished by the smallness of the telescope.

The following times are 8^h 0^m slow of Greenwich. They are Pacific Standard Time.

First contact with the shadow at 8^h 0^m 40^s. At 8^h 1^m 40^s the limb was faint and scarcely visible. Contact of shadow with Aristarchus 8^h 6^m 20^s. 8^h 15^m.—There is no color yet, the shadow is a cold gray. The limb is easy to see. 8^h 18^m 0^s—Cape Laplace touched by shadow. 8^h 18^m 25^s—Contact with Pythias. 8^h 20^m 5^s—Center of Copernicus. At about 8^h 18^m a slight warmth appeared at limb. 8^h 24^m 35^s—Center of Plato. 8^h 30^m—Warm reddish color along the limb but not symmetrical, it extends northerly from the center of shadow. 8^h 32^m 30^s—Contact with east edge of Mare Serenitatis. 8^h 34^m 40^s—Contact center of Manilius. 8^h 37^m—The reddish color extends for an arc of some 30° or 40°. It is north of the central part of obscured limb. 8^h 39^m 20^s—Tycho cut centrally by shadow. 8^h 43^m—To the naked eye the north east part of the disc decidedly of a warm color. The entire disc is visible. Sky clear and rapidly darkening. In the telescope the northeast portion bright warm color. The southeast part is

dull and dark with scarcely any trace of color. Where visible the color is confined to a small region near and at the northeast limb. $8^h\ 40^m$—A large portion of the eclipsed disc of a warm color but the brightest reddest part is confined to small region near northeast limb. To the naked eye the northeast part is a clear reddish color. The southeast part is darker but all of the eclipsed part of a warm color. $8^h\ 53^m$—In the telescope all the northeast quadrant is of a beautiful warm glow. The southeast is warmish but not much so. It is nearly cold in color. For about 7′ the advancing shadow is a cold steely blue. $8^h\ 50^m$—To the naked eye all tne north part is a fine red. The southeast part a dirty warm color. Some of the darker regions of the Moon seen with the naked eye. $9^h\ 6^m\ 0^s$—Totality—decided and good. All the northern part a light reddish color but not very clear. With eye the upper half is reddish. In the telescope all the lunar details very clearly seen. $9^h\ 20^m$—To the naked eye the brightish red color is north and a little west near the northwest limb. At east limb it is bluish in telescope, but to the naked eye the disc is all more or less red. $10^h\ 47^m\ 0^s$—End of totality suspected. $10^h\ 48\frac{1}{2}^m$—End of totality certain. $11^h\ 0^m$—To the naked eye the eclipsed Moon is uniformly pale reddish color. The dark regions seen easily with the naked eye. $11^h\ 8^m$—To the naked eye the eclipsed Moon is uniformly pale red except where the *maria* are. $11^h\ 11^m\ 25^s$—Tycho centrally cut by shadow. $11^h\ 12^m\ 0^s$—Contact with west edge of Copernicus. $11^h\ 53^m\ 0^s$—End of eclipse, leaves shadow. To my mind this was a rather dark eclipse, certainly dark compared with that of June 11, 1881, possibly darker than that of 1888, July, which was observed here under nearly the same conditions as the present one.

During totality the sky was dark and the milky way shone as brightly as if no Moon was present. It seemed to have no effect in deadening the faint stars and the milky way.

I felt almost positive that I could see the glow of the Gegenschein about the eclipsed moon.

A number of photographs were made of the partial phases and during totality with the Willard lens. Those during totality are very beautiful and clear, the details showing beautifully and the Moon perfectly sharp, the following being carefully attended to. Indeed I never saw a picture of the Moon making it so beautifully globular as do these pictures of the total phase. The accuracy of guiding is shown by the uniformity of the star trails. The shortest exposure given during totality was 5^m. With this every detail comes out clearly and the Moon stands out like a beautiful ball. The results are extremely satisfactory and pleasing.

E. E. BARNARD.

Mt. Hamilton, California, 1895, Sept. 5.

The Lunar Eclipse at Lowe Observatory.—The total eclipse of the Moon was observed here in a cloudless sky. Fearing lest the view should be cut off by the fog, which often fills the San Gabriel valley, a throng of visitors came up the mountain from Los Angeles, Pasadena and other adjacent towns to the Observatory, to which the fog seldom rises, and were repaid by uninterrupted observation of all the beautiful phenomena. Though the appearance was quite similar to that of March last yet there were points of difference. Aristarchus, which at that time glowed with such brightness as to attract the attention of the most careless observer, was, on this occasion, a very inconspicuous object, not noticeable unless looked for.

One phenomenon which I had never before seen nor read of was the following:

On the Moon's upper limb was a pale blue segment, straight and sharply defined, comprised between its arc and chord. I estimated the versed sine in length to be equal to about one-fiftieth of the Moon's diameter. To this feature my attention was first directed by Professor Lowe who saw it with a field-glass, in which instrument I find many others observed it, also. Through the finder of the great telescope it was visible, also, though less conspicuous in the great glass, and easy to escape detection were its place and appearance not previously known.

To account for this appearance Professor Lowe advanced the theory that it was sunlight refracted by the Earth's atmosphere at the surface of the Pacific Ocean, but the hypothesis seems untenable, as it fails to account for the size and shape of the blue portion, as well as the sharpness of the chord.

I am anxious to learn if this phenomenon was witnessed elsewhere.

LEWIS SWIFT.

Lowe Observatory, Echo Mountain, Cal.
Sept. 9, 1895.

The Total Eclipse at Alta, Iowa.—The total lunar eclipse was well observed here on the night of Sept. 3rd and 4th. The sky was beautifully clear, the atmosphere steady and the seeing almost perfect.

I used my 3 inch telescope, magnifying power 64.

My attention was given chiefly to recording the various shades of color on the Moon during its progress through the Earth's shadow. This was done at intervals of about ten minutes, both with the naked eye and through the telescope.

The following are a part of my notes, the times noted are Central Standard.

$9^h\ 55^m$—Light orange shading appearing at N. E. edge. $10^h\ 00^m$—Slight indentation just visible to the naked eye. $10^h\ 10^m$—The segment of the Moon now in the shadow is quite invisible to the naked eye, but plainly seen with telescope, covered with a greenish-black shade. $10^h\ 17^m$—Shadow touching edge of Copernicus. $10^h\ 18\frac{1}{2}^m$—Shadow bisecting Copernicus. $10^h\ 20^m$—Shadow entirely covering Copernicus. $10^h\ 30^m$—Shadow near E. limb is now quite dark green and shades off to a lighter green color near edge of shadow. $10^h\ 35^m$—To the naked eye the shadow is now a light brown-red, but through the telescope it appears of a smoky green color. $10^h\ 45^m$—The northern half is a dusky copper hue and the southern portion a lighter shade of greenish-black. $11^h\ 00^m$—Southern portion is now bluish-green. $11^h\ 03^m$—Southern portion is pretty pale blue color. $11^h\ 05^m$—Last line of sunlight now at edge. $11^h\ 06^m$—Last trace of sunlight disappears. $11^h\ 25^m$—The lunar disc is now a bright copper color except in extreme S. portion, which is a slate color, to the naked eye it appears dusky copper. $11^h\ 50^m$—Now nearly middle of totality, it is a uniform light orange color through telescope. $12^h\ 10^m$—Bright segment of light orange along E. edge, visible to naked eye. $12^h\ 20^m$—The bright portion E. is much longer and brighter. $12^h\ 30^m$—The W. portion is becoming a dusky red color. $12^h\ 40^m$—E. side growing brighter yellow. $12^h\ 45^m$—Tinge of sunlight just visible. $12^h\ 48^m$—True sunlight appears. $12^h\ 50^m$—The shadow is now a decided coppery hue, observations ceased.

DAVID E. HADDEN.

Alta, Iowa, Sept. 4th, 1895.

Solutions of problems in the May number have been received from the following:

Mr. Thomas Lindsay, of Toronto, solved numbers 2, 3 4, 5.

Mr. Orrin E. Harmon, of Chehalis, Wash., solved numbers 1, 2, 3, 4, 5 and 7.

Mr. S. A. Saunder, of Crowthorne, Berks, England, solved numbers 1, 2, 3, 4 5, 6 and 7.

J. M.

Note to problem 1. A clerical error was committed—the second term of the second number should be plus.